Pacific Island Network
Vital Signs Monitoring Plan:
Phase III Report

Appendix E: Topical Working Group Report – Air Quality and Climate

Karin Schlappa (HPI-CESU)

Pacific Island Network (PACN)

Territory of Guam
War in the Pacific National Historical Park (WAPA)

Commonwealth of the Northern Mariana Islands
American Memorial Park, Saipan (AMME)

Territory of American Samoa
National Park of American Samoa (NPSA)

State of Hawaii
USS Arizona Memorial, Oahu (USAR)
Kalaupapa National Historical Park, Molokai (KALA)
Haleakala National Park, Maui (HALE)
Ala Kahakai National Historic Trail, Hawaii (ALKA)
Puukohola Heiau National Historic Site, Hawaii (PUHE)
Kaloko-Honokohau National Historical Park, Hawaii (KAHO)
Puuhonua o Honaunau National Historical Park, Hawaii (PUHO)
Hawaii Volcanoes National Park, Hawaii (HAVO)

http://science.nature.nps.gov/im/units/pacn/monitoring/plan/

Suggested citation:

Schlappa, K. 2005. Supporting Documents: Air Quality and Climate Report. *In*: L. HaySmith, F. L. Klasner, S. H. Stephens, and G. H. Dicus. Pacific Island Network Vital Signs Monitoring Plan: Phase III (draft) report. National Park Service, Pacific Island Network, Hawaii National Park, HI.

Last revision: 16 May 2005

Organization contact information:

National Park Service (NPS), Inventory and Monitoring Program, Pacific Island Network, PO Box 52, Hawaii National Park, HI 96718, phone: 808-985-6180, fax: 808-985-6111, http://science.nature.nps.gov/im/units/pacn/monitoring/plan/

Hawaii-Pacific Islands Cooperative Ecosystems Studies Unit (HPI-CESU), University of Hawaii at Manoa, 3190 Maile Way, St. John Hall #408, Honolulu, HI 96822-2279

Acknowledgements:

This appendix was prepared with assistance from the Hawaii-Pacific Islands Cooperative Ecosystems Studies Unit (HPI-CESU).

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EXECUTIVE SUMMARY

Air quality and climate, as addressed in this report, incorporate all aspects of natural and anthropogenic atmospheric conditions, including meteorology, climate, climate change, air quality related values, air quality or air pollution, and other related parameters incorporated in these categories. Solar radiation (photosynthetically active radiation and ultraviolet radiation) is also addressed within this workgroup. Excluded from this report are NPS-Air Resource Division programs of natural sounds (soundscapes) and night skies (lightscapes). Air quality and climate are generally regional or global issues and, as such, within the Pacific Island Network these issues transcend park boundaries. However, the focus of this report is on the impacts on natural resources present within the national parks.

The recommended basic goals of the NPS monitoring program are to define baseline air quality conditions, identify climate 'normal' conditions, as well as to record pollution, extreme events and disturbances and their impacts. The aspiration of the National Park Service is to identify natural conditions, (i.e. conditions unaffected by human activity) and strive to maintain or return to these conditions. This requires identifying anthropogenic sources of change and may involve pressing for changes in, or enforcement of, policy and legislation to minimize the effect of human activities. Climate and air quality are basic parameters that affect virtually all other ecosystem and park natural resource components. Therefore, priorities for air quality and climate monitoring will need to also reflect those of other topics, such as water quality and geology.

The legal and mandated basis for addressing air quality concerns in the National Parks is the Clean Air Act and subsequent amendments, along with the NPS Organic Act. HAVO is the only park with an explicit air quality monitoring program due to immediate safety concerns related to emissions from Kilauea, the active volcano located in the park. Mandates for monitoring climate related issues are not as strict as for air quality. Management considerations during tropical cyclones (hurricanes/typhoons) are probably the climate issue most commonly addressed by park management in PACN parks.

The PACN region includes islands that span nearly all of the world's major climate zones, from tropical to alpine. Broad-scale atmospheric circulation processes produce prevailing trade-winds, a trade wind inversion and distinct windward and leeward areas. Climate has been identified as a primary ecosystem driver. It affects virtually all natural resources and is important for understanding long-term trends as well as spatial distribution of ecosystem processes. Reports of the Intergovernmental Panel on Climate Change (IPCC 2001) and the 'Pacific Assessment' (Shea et al. 2001), a contribution to the National Assessment of the Consequences of Climate Variability and Change as part of the U.S. Global Change Research Program, identify small islands as particularly vulnerable to the effects of climate variability and human induced climate change, even though they account for less than 1% of global greenhouse gas emissions. Ecosystem effects are particularly harsh because habitats for many native species have already become fragmented due to land use and the presence of introduced plant and animal species. Climate variability may reduce some of these habitats even further or eliminate them altogether. In addition, the spread of alien species is often facilitated by extreme events associated with climate variability such as prolonged droughts or increased storm frequency. Climate and climate change issues currently affecting natural resources in the PACN include effects of increased sea surface temperatures and UV radiation on coral reefs, effects of sea level

rise on shoreline and coastal communities and the spread of avian malaria and other vector borne diseases due to changes in temperature and rainfall patterns. In addition, the effects of extreme events such as prolonged, ENSO-related droughts and a possible increase in frequency and intensity of tropical cyclones and associated flooding are of concern.

The needs for weather monitoring in the national parks include: fire prediction, issues relating to visitor health and safety, characterization of basic ecosystem properties, as well as analysis of ecosystem effects of climate variability. Several parks or park units in the PACN monitor none or just very little of the meteorological parameters. Adding weather stations would be desirable for some parks; alternatively, for many parks it is possible to obtain adequate meteorological data from nearby stations maintained by the National Weather Service, the U.S. Geological Survey or others. The National Park Service Inventory and Monitoring program is in the process of establishing a Climate and Air Quality database that would tap into these existing sources to provide weather information. Climate mapping –temperature and rainfall- for the region has been prepared by the Natural Resources Conservation Service programs in the past and is currently being updated for the period of 1971-2000 at a finer spatial resolution.

Within the PACN region, increasing urbanization and local land-use practices are having negative impacts on air quality. Plumes of pollution and mineral dust have also been recorded at NOAA CMDL (National Atmospheric and Oceanic Administration, Climate Monitoring and Diagnostics Laboratory) observatories in Hawaii and American Samoa. However, geographic isolation shields PACN parks from most anthropogenic pollution influences. Air quality and related values in the PACN are most notably affected by volcanic activity, with potential effects on climate. Effects outside the island of Hawaii are sporadic, while on the island of Hawaii volcanic emissions present a long-term source of pollution, often leading to severe deterioration of air quality at HAVO.

The desire to protect human health and the health of natural systems is the most basic need for monitoring air quality. In the case of the two Class I areas in the PACN, HAVO and HALE, monitoring of visibility is legally mandated for this reason. Another incentive for monitoring air quality is the desire to understand the role of atmospheric deposition in nutrient cycling and its influence on ecosystem processes. Within the PACN research on atmospheric nutrient inputs occurs only at HAVO and HALE through research projects by academic institutions and federal agencies and through federal monitoring networks, such as CASTNET (Clean Air Status and Trends Network), PRIMENet (Park Research and Intensive Monitoring of Ecosystems Network), IMPROVE (Interagency Monitoring of Protected Visual Environments) and NADP (National Atmospheric Deposition Program). Within the PACN region but external to parks, NOAA CMDL carries out extensive research of atmospheric parameters, including gases, aerosols, solar radiation at observatories in Hawaii and American Samoa. The University of Guam Water and Environmental Research Institute, Stanford University, the University of Hawaii, the U.S. Geological Survey also conduct research relating to air quality, atmospheric deposition, and hydrology on several islands in the PACN. This collective pool of expertise has been invaluable in assisting to identify and summarize air quality and climate issues in the PACN region.

INTRODUCTION

SCOPE OF TOPIC AREA

Air quality and climate, as addressed in this report, incorporate all aspects of natural and anthropogenic atmospheric conditions, including: meteorology, climate, climate change, air quality related values, air quality or air pollution, and other parameters related to these categories. Solar radiation (photosynthetically active radiation and ultraviolet radiation) is also addressed within this workgroup. Excluded from this report are night skies (lightscapes) and the NPS-Air Resource Division natural sounds (soundscapes) program. Air quality and climate are generally regional or global issues. Not surprisingly, within the Pacific Island Network (PACN) these issues transcend park boundaries. Nonetheless, the focus of this report is the impact of air quality and climate factors on the natural resources present within the national parks.

BACKGROUND

Climate change is a natural phenomenon. However, human induced increases in greenhouse gas concentrations are expected to lead to unprecedented rapid change in climate parameters, leaving little time for natural systems to adapt. Island ecosystems are particularly vulnerable to the effects of climate change due to a combination of their geographic isolation and small size. In general, endemism of plant and animal species on islands is higher compared to mainland species. Island species occupy much more restricted habitats, yet already suffer from the effect of other stressors such as alien species invasions and problems associated with rapidly growing human populations. Climate change will affect marine as well as terrestrial systems due to the impact of rising sea and air temperatures, sea level rise, increased erosion and runoff, changes to wind and precipitation patterns and possibly an increase in intensity and frequency of storms. Monitoring of climate parameters in national parks will provide data to evaluate whether ecosystem changes are correlated with climate change. While nothing can be done by park managers to reverse climate change, monitoring data will yield information that can be used for management decisions regarding habitats or species that are at risk.

Air quality degradation can have extremely detrimental effects on ecosystems as well as human health. National parks in the contiguous U.S. have focused monitoring efforts and scientific studies on the effects of air pollution. With the exception of the two largest parks (HAVO and HALE), little or no monitoring of air quality and deposition amounts has occurred in PACN parks. Air quality on the remote islands in the PACN is generally good with the exception of the natural but polluting influence of volcanic eruptions. However, rapid population growth and the associated increase in vehicular and industrial emissions are of concern. It is important to establish baseline conditions against which future measurements can be evaluated so that action can be taken to prevent deterioration of natural systems.

MONITORING GOALS AND OBJECTIVES

The primary goal of air quality and climate monitoring in the PACN is to document or define ‘baseline’ conditions in air quality and ‘normal’ climatic conditions, including spatial and temporal variability. Knowledge of these conditions can then be used to evaluate the effects on other natural resources and air quality related values (AQRVs). The latter are defined as resources sensitive to air quality, including wildlife, vegetation, water quality, soils, visibility, and cultural resources. A further goal of monitoring is to provide early indicators of changes in air quality and climate, especially climate forcing events. This information will ensure that the effects of such changes on other natural resources can be documented. Furthermore it will provide land managers an opportunity for pro-active management. Models of weather, air pollution dispersal, and deposition patterns, incorporating complex island and orographic influences on airflow, are needed in order to interpret nearly all research and monitoring conducted in the parks.

Monitoring climate and air quality parameters will facilitate meeting the NPS Air Resources Division principal monitoring objectives which are: 1) determine levels of air pollutants in parks and correlate to observed effects; 2) identify and assess trends in air quality; 3) determine compliance with National Ambient Air Quality Standards; 4) provide data for the development and revision of national and regional air pollution control policies; 5) provide data for atmospheric model development and evaluation; 6) use information to inform public about conditions/trends in national parks; and 7) determine which air pollutants in parks contribute to visibility impairment (NPS 2002b).

Examples of some of the more specific issues that monitoring of air quality, air quality related values, and climate could benefit are listed below.

- What are the current spatial and temporal climate conditions and how might altered patterns or trends (i.e., climate change) affect hydrologic cycles, fire, native and invasive species, disease, etc?
- How do atmospheric conditions, such as dust events, haze, UV radiation, temperature affect coral reef and other aquatic systems?
- How do atmospheric deposition patterns and trends influence the success of species invasions/succession?
- Are terrestrial resources changing as a result of volcanic or anthropogenic emissions? Are there changes to vegetation, soil chemistry and microbe populations?
- What role does atmospheric long-range transport play in providing basic ecosystem nutrients and pollutants?
- What influence do modern urbanization, power production, industrial activities, and land use change have on visibility resources? Compared with marine and volcanic influences?
- How is local air quality, especially when influenced by volcanic emissions, affecting human health? How do the effects vary for short term visitors versus residents subjected to chronic exposure?
- What role do air quality and volcanic emissions play in the geologic cycles of our island systems?
- How do atmospheric particles and gases whether of volcanic, marine, and anthropogenic origin affect cultural artifacts/resources?

LEGISLATION AND POLICY

As a federal agency, NPS operates under a hierarchy of legislative mandates, including federal laws, executive orders, Department of the Interior and NPS policies and directives, as well as county, state, commonwealth, and territorial regulations. Further, management of submerged resources is complicated by jurisdictional or administrative issues that are often managerially more challenging than similar issues on land. These complexities require NPS to cooperate with numerous and often overlapping federal and local agencies to achieve its objectives.

I & M - Natural Resource Challenge

The Natural Resource Challenge (NRC), initiated in 1999, is an action plan for preserving natural resources through the National Park Service (NPS). The NRC assisted NPS to establish 32 Inventory and Monitoring networks, which includes 270 National Parks. The networks group parks that share geographical and natural resource characteristics. The Inventory and Monitoring (I&M) Program is designed to first complete basic inventories of natural resources in parks, on which to base long-term monitoring efforts. Monitoring programs are based on monitoring critical parameters (Vital Signs) within each network to incorporate into natural resource management and decision-making. “Vital Signs are measurable, early warning signals that indicate changes that could impair the long-term health of natural systems” (NPS 2003).

The NRC (NPS 1999) lists air quality specifically as one of the challenges in natural resource preservation. The ‘Guidance on Air Quality and Air Quality Related Values for Vital Signs Monitoring in National Parks’ (Maniero 2001), states that “long-term protection of air quality in the National Park System requires a sustained effort to monitor air quality and related values and to enhance scientific understanding of how air pollution affects resources.” The vital signs monitoring plan and this report address these issues. Specific minimum and further desired parameters to monitor for assessing air quality, climate and meteorological conditions are identified in the Natural Resources Inventory & Monitoring Guideline brochure (NPS no date) and addressed throughout this document.

Federal

The National Park Service’s air resource management-related responsibility is grounded in several acts of Congress, especially the Clean Air Act and the NPS Organic Act (see the discussion of general legislative authorities in the main document, Chapter1 section A-2 and B-5). Other laws provide a variety of opportunities for NPS action to manage air resources and protect park resources and values that are dependent upon good air quality as described in Reference Manual #77 (NPS 2002). These include the National Environmental Policy Act, the Wilderness Act, the Endangered Species Act, and the Surface Mining Control and Reclamation Act. The enabling legislation or the accompanying legislative histories for numerous individual parks also indicate Congress' clear intention of protecting resources and values that might be sensitive to air pollution, e.g., superlative scenic features that depend on good visibility.

The Clean Air Act

The main purpose of the Clean Air Act (CAA) is to protect and enhance the nation's air quality in order to promote the public health and welfare. The Act establishes specific programs that provide special protection for air resources and AQRVs associated with NPS units. For example, sections 160-169 of the Act establish a program to prevent significant deterioration (PSD) of air quality in ‘clean’ air regions of the country. Clean air regions are areas of the country where pollutant concentrations are below the national ambient air quality standards (NAAQS). The purpose of the PSD program is to protect resources that might be sensitive to pollutant concentrations lower than the NAAQS and "to preserve, protect and enhance the air quality in national parks, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic or historic value". In section 169A of the Act, Congress also established a national goal of remedying any existing and preventing any future human-caused visibility impairment in mandatory Class I areas. These are defined by the CAA as national parks greater than 6,000 acres, wilderness areas and national memorial parks greater than 5,000 acres, and international parks that existed as of August 1977. Two parks in the PACN, Hawaii Volcanoes and Haleakala National Parks, are Class I areas. All clean air regions not defined as Class I areas are Class II areas. This includes most of the units of the National Park System. In these areas moderate increases of pollutant concentrations over baseline values are allowed. However, NPS can have input in some activities such as State Implementation Plan proceedings or new source reviews that affect the air quality of Class II areas. In the CAA amendments of 1977 Congress explicitly stated NPS's authority and duty to protect park resources from air pollution-related damage. The 1990 amendments to the Act added provisions that confer additional responsibilities on the NPS to control internal emissions. At a minimum, the NPS must ensure that internal activities comply with all applicable air pollution control laws and regulations. The CAA places constraints on any development or management activities within parks that could affect air quality by requiring parks to comply with all federal, state, and local air pollution control laws and regulations.

State and local governments have the primary responsibility to develop, implement, and enforce air pollution prevention and control plans. The CAA generally requires states to consult with NPS when developing and revising a State Implementation Plan (SIP) that might affect units of the National Park System, regardless of the classification of the area. Congress specifically requires NPS involvement in the development of PSD and visibility protection SIPs. The CAA provides the highest degree of protection for Class I areas. With the CAA Congress gave NPS an affirmative responsibility to protect air quality related values of Class I areas. Congress directed that, when a major stationary source of air pollution is constructed and the emissions from this source are likely to affect a Class I area, NPS must be consulted in the permitting process. Long-term data for air quality and possible effects are often necessary to make informed decisions on SIPs and the permitting process.

If there is existing visibility impairment in any Class I area NPS is also charged with notifying states and identifying the suspected source(s) of the impairment, if possible. If the affected state has not adopted a visibility protection SIP the EPA must be notified. The state or the EPA must determine if the impairment is reasonably attributable to a specific source or small group of sources. Monitoring or modeling can be used to assess whether the source(s) causes or contributes to significant visibility impairment. See 40 CFR 51.300 et seq. for detailed regulatory requirements related to visibility protection.

NATIONAL PARK SERVICE

Park Enabling Legislation

Each of the parks in the PACN has enabling legislation that describes the primary purpose and mission of the park. The Exception is USAR which operates under a Memorandum of Understanding with the US Navy. Park enabling legislation often contains specific directives requiring the conservation of key natural resources. For example, enabling Legislation for KAHO states that, “Sec. 505 (d) (4) – Secretary shall consult with and may enter into agreements with other government entities and private landowners to establish adequate controls on air and water quality and the scenic and aesthetic values of the surrounding land and water areas…" Enabling legislation for the other PACN parks does not mention air quality specifically, but includes directives to protect and preserve cultural and historical sites and natural features. Some excerpts are listed below:

- WAPA "…to conserve and interpret outstanding natural, scenic and historic values…"
- NPSA "The loss of these [tropical] forests leads to the extinction of species, lessening the world's biological diversity, reduces the potential for new medicines and crops and increases carbon dioxide levels in the atmosphere contributing to the greenhouse effect that is altering the global climate…………..The purpose of this act is to preserve and protect the tropical forest…"
- KALA the natural resources are addressed as "scenic values" in the establishment act.
- HALE and HAVO legislation mentions the protection of "natural curiosities or wonders."
- ALKA legislation mentions protection of "a variety of significant cultural and natural resources"

These statements can be interpreted to include protection from anthropogenic changes to air quality or climate parameters, as these can have significant harmful impacts on structures, ecosystems and scenic values.

NPS Management Policies

According to the 2001 Management Policies (NPS 2001), "The National Park Service has a responsibility to protect air quality under both the 1916 Organic Act and the Clean Air Act. Accordingly, the Service will seek to perpetuate the best possible air quality in parks to: (1) preserve natural resources and systems; (2) preserve cultural resources; and (3) sustain visitor enjoyment, human health, and scenic vistas.

Vegetation, visibility, water quality, wildlife, historic and pre-historic structures and objects, cultural landscapes, and most other elements of a park environment are sensitive to air pollution and are referred to as "air quality- related values." The Service will assume an aggressive role in promoting and pursuing measures to protect these values from the adverse impacts of air pollution." Furthermore, the Service will:

- Inventory the air quality- related values associated with each park;
- Monitor and document the condition of air quality and related values;
- Evaluate air pollution impacts, and identify causes;
- Minimize air quality pollution emissions associated with park operations, including the use of prescribed fire and visitor use activities; and
- Ensure healthful indoor air quality in NPS facilities.

In regards to weather and climate, the 2001 Management Policies state "parks containing significant natural resources will gather and maintain baseline climatological data for perpetual reference." The policies also state that the Service will "…seek to prevent weather-modification activities conducted by others from affecting park weather, climate, and resources."

According to Reference Manual #77, Natural Resource Management (NPS 2002), Hawaii Volcanoes and Haleakala National Parks are 'Class I' areas, no PACN parks are 'Class II floor areas', but all other PACN parks are 'Class II' areas. Identified National Park Service Mandatory Class I Area Integral Vistas include: Haleakala NP, Red Hill Observatory (observation point), 280º - 320º and 120º - 165º (view angles) and Hawaii Volcanoes NP, Hawaii Volcanoes Observatory (observation point), 220º - 350º (view angles). There are no regulations requiring special protection of these integral vistas, but the Service will strive to protect these park-related resources through cooperative means. Guidance for 'ozone health advisory programs' has also been prepared. There is no official guidance for SO_2 advisory programs.

Park-specific Management Polices

It is assumed that all parks are affected by tropical cyclones, and that management actions are taken in accordance with National Weather Service and local Civil Defense policies. General, park-specific policies related to poor air quality conditions, AQRVs, activities or events that affect air quality, or significant climatic conditions are identified below.

- HALE - Visibility goals for designated viewsheds are identified in the General Management Plan.
- PUHE - Air quality and smoke management are addressed in the (draft) Fire Management Plan.
- HAVO - The park, USGS-HVO, and NPS-ARD jointly maintain a vog (volcanic smog) alert system. Operational policies related to the hazard levels in this vog alert system are identified in the SO_2 Response Stand-Down Table which is kept at the HAVO dispatch office. Signs alerting visitors to the health hazards of volcanic fumes are also posted in zones routinely experiencing strong vog or laze (Halemaumau crater, Steam Vents, Sulfur Banks, lava ocean entry area). The dangers are also addressed in visitor brochures.
- The other national parks in the PACN do, at this time not have any specific policies. Development of Fire Management Plans, which often address air quality management concerns, is underway for several Hawaii national parks.

REGIONAL

Hawaii

The Department of Health (DOH) policy on fire smoke whether resulting from natural, suppression, or controlled fires does not require permits. However, notification of the DOH is required. A haze/smoke SIP for the state of Hawaii is being developed. The DOH also conducts air quality monitoring throughout the state in accordance with EPA and state regulations. The Department of Civil Defense in cooperation with the National Weather Service issues tropical cyclone (hurricane), storm and flood watches and warnings and is in charge of responding to natural disaster emergencies.

Guam

The Guam EPA Air Pollution Control Program is responsible for the implementation and enforcement of Guam's Air Pollution Control Standards and Regulations. The agency currently only monitors air quality in the event of an emergency such as a large fire. The Guam Office of Civil Defense is responsible for coordinating and facilitating all government, military and federal agencies in mitigating, preparing for and responding to all types of emergencies including droughts, floods and tropical cyclones (typhoons). Official watches and warnings for these emergency conditions are posted in cooperation with the National Weather Service.

Commonwealth of the Northern Mariana Islands (CNMI)

The Office of the Governor CNMI Division of Environmental Quality has an Air Toxics Management branch, but at this time no air quality monitoring is conducted. The CNMI Emergency Management Office is responsible for responding to all emergency calls including storms, topical cyclones (typhoons) and floods.

American Samoa

Part of the mission of the American Samoa Environmental Protection Agency (ASEPA) is to develop and implement programs to protect the environment and public health from harmful impacts on air quality. At this point ASEPA is not conducting any air quality monitoring. The Territorial Emergency Management Coordinating Office of American Samoa has the primary mission to protect the lives and property of the Territory's people from the adverse effects of natural and manmade disasters including, but not limited to tropical cyclones and floods.

ECOLOGICAL CONTEXT

GEOGRAPHY

All the PACN network parks are located on tropical islands in the Pacific Ocean. Eight of the parks are in the Hawaiian Islands in the Central Pacific between 19 and 22 degrees North latitude. HAVO, KAHO, PUHE, PUHO, and the recently designated ALKA are on the island of Hawaii, the youngest of the main Hawaiian Islands at the southern and eastern end of the archipelago. HAVO is located on the southeast slope of Hawaii Island, where it extends from sea level to the summits of Kilauea and Mauna Loa Volcanoes. The newly designated Kahuku unit of HAVO is positioned on southern Mauna Loa and extends down both the eastern and western flanks of the volcano. PUHE, KAHO, and PUHO are coastal parks of the western side of the island. KAHO is centrally located with PUHE to the north and PUHO to the south. HALE is on Maui, the second youngest Hawaiian Island. HALE extends from sea level to the summit of East Maui. KALA is on a peninsula projecting from the north shore of Molokai, centrally located in the main Hawaiian Islands. USAR is within Pearl Harbor on southern or leeward Oahu. Two PACN parks are situated in the western Pacific Ocean between 13 and 15 degrees north latitude in Micronesia. WAPA is on the western side of the island of Guam and AMME is on the west coast of Saipan, one of the Northern Mariana Islands. NPSA is on the Polynesian islands of American Samoa, approximately 14 degrees south latitude. One unit of NPSA is on the island of Tutuila, and three others are on Tau, Ofu, and Olosega of the Manua Island group 96 km (60 miles) east of Tutuila.

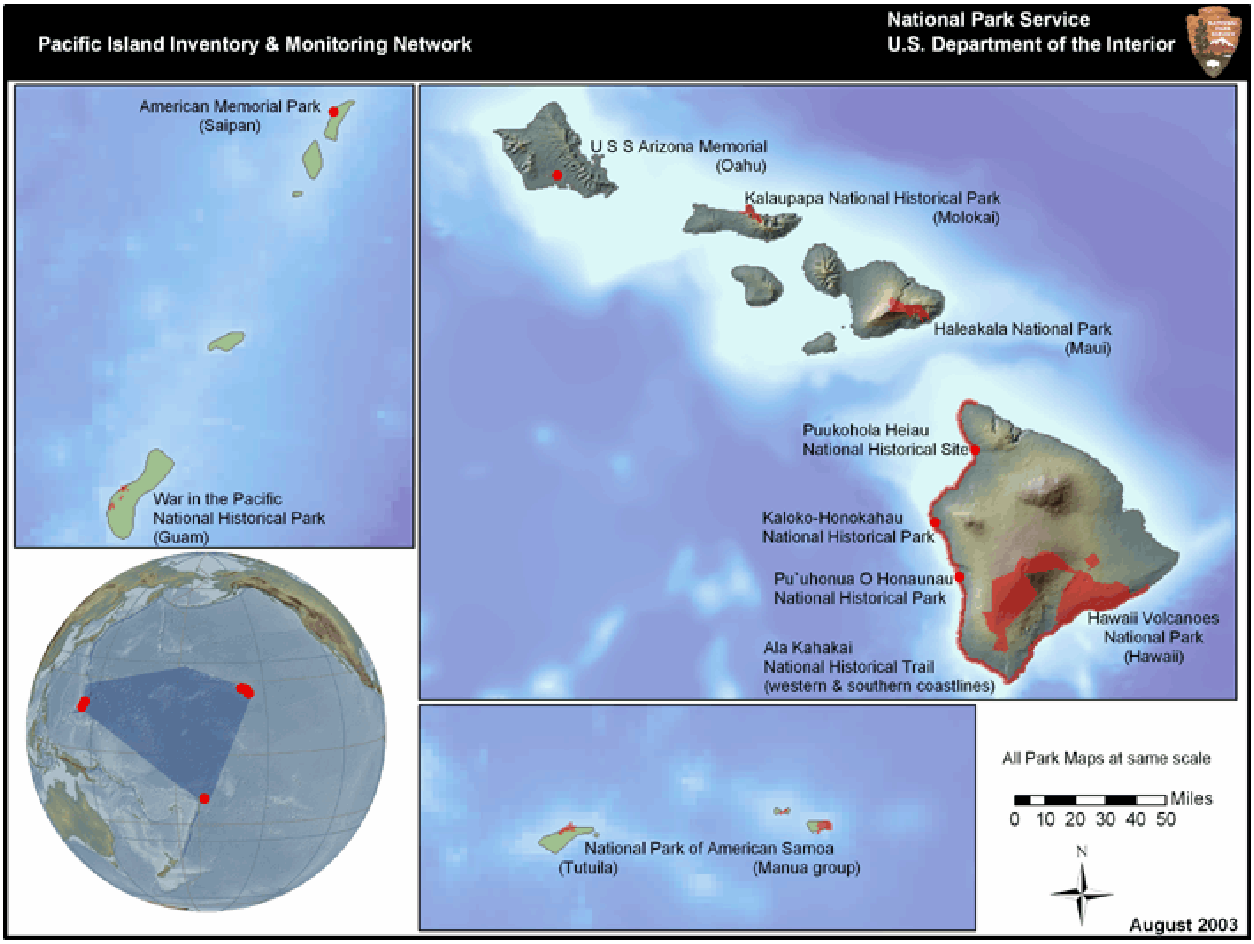

Figure 1. Pacific Island Inventory and Monitoring Network

GEOLOGY

The parks of the Western Pacific (WAPA, AMME) are on the islands of Guam and Saipan which have long-extinct volcanoes. These islands have complicated geologic origins involving both volcanism and subduction of the Marianas Trench. Hence, the northern half of Guam and portions of Saipan have limestone substrates elevated above a weathered volcanic base. WAPA units are on the volcanic substrates of the southern half of Guam, and at least one unit includes elevated limestone caps.

The islands of American Samoa and Hawaii are oceanic volcanic islands arising from hotspots. The oldest of the Samoan Islands are dated at more than two million years, but there was volcanic activity between Tau and Olosega approximately 150 years ago (Whistler 1994). In Hawaii, HALE protects the summit of the inactive Haleakala Volcano and its impressive crater, which is the result of stream erosion, the merging of Kaupo and Keanae Valleys, and subsequent volcanic activity. KALA encompasses the Kalaupapa peninsula, formed on the north shore of Molokai during the Pleistocene (MacDonald and Abbott 1970). The volcanoes on both Molokai and Oahu are extinct.

The five parks on Hawaii Island are on active or dormant volcanoes. A significant portion of HAVO is covered with recent lava flows that are sparsely vegetated. HAVO also contains the rift zones and summit calderas of both Mauna Loa and Kilauea Volcanoes, two of the most active volcanoes on earth. PUHO is on prehistoric pahoehoe flows of Mauna Loa, and PUHE substrates are old weathered soils of Kohala Volcano. All substrates of KAHO are flows from Hualalai Volcano less than 10,000 years old, including one sparsely-vegetated lava flow dated at 1,000-3,000 years (Moore *et al.*1987).

ELEVATION GRADIENTS

Among the Hawaiian parks, HAVO and HALE have the greatest elevational range, extending from sea level to the summits of tall volcanoes >3,000 m (>10,000 ft) in elevation. KALA has an elevational range from sea level to almost 1,220 m (4,000 ft) elevation. The three parks of leeward Hawaii Island are coastal parks and extend upslope to an elevations less than 100 m. ALKA is also in the coastal lowlands of western and southern Hawaii Island.

Among the three Western Pacific parks, AMME is restricted to coastal lowlands on the western shore of Saipan. WAPA includes both coastal units and inland sites on the slopes of Mt. Alifan and Mt. Tenjo, with one unit extending above 305 m (1,000 ft) in elevation. NPSA is composed of four units; Ofu and Olosega are largely coastal but the Tutuila and Tau units range from sea level to 491 m (1,610 ft) and 966 m (3,170 ft) elevation, respectively. The planned expansion of NPSA on Ofu and Olosega will include the summits of both islands, which are 499 m (1,621 ft) and 639 m (2,096 ft) respectively.

RAINFALL AND CLIMATE

The largest two Hawaiian parks, HAVO and HALE, include within their boundaries several climatic zones with a range of rainfall regimes. HAVO contains two of the four rainfall minima of Hawaii Island, the Kau Desert with mean annual rainfall <750 mm and the interior lands of Mauna Loa. The highest mean annual rainfall within the park is found in Olaa Tract, a rain forest with >4,000 mm per year (Giambelluca *et al*. 1986). In general, the eastern windward portion of HAVO has high rainfall, which diminishes upslope, particularly above the trade wind inversion layer near 1,830 m (6,000 ft) elevation. The upper elevations of the park are moist to very dry, and the summit of Mauna Loa receives on average <500 mm precipitation. The leeward, western portions of HAVO are in rain shadows of Mauna Loa and Kilauea summit, and are typically dry.

HALE also has a range of climates, as it extends from sea level on the windward, eastern slope of Haleakala to the summit of East Maui. This park also includes lands in the leeward rain shadow of Haleakala, down to 1,220 m (4,000 ft) elevation. Annual precipitation in the park varies from 1,250 mm in the Crater, the southern slope, and Kaupo Gap to >6,000 mm on the upper northeastern slopes of Haleakala. KALA, on the north shore of Molokai receives 1,000 mm of precipitation annually at sea level and >3,000 mm at the upper elevations of Waikolu Valley (Giambelluca *et al*. 1986). The USAR on Oahu is located within Pearl Harbor on the dry leeward side of the island in an area than has on average 600 mm rainfall per year.

The four Hawaii Island parks are in relatively low rainfall areas with constant warm temperatures and pronounced daily wind patterns of land and sea breezes (Blumenstock and Price 1967). KAHO has a mean annual rainfall of approximately 600 mm and a seasonal climate with higher rainfall during summer months (Canfield 1990). The climate of PUHO is similar to that of KAHO, with mean annual precipitation of 659 mm. PUHE is located within one of the four rainfall minima of the island of Hawaii and receives <250 mm of rain annually (Giambelluca *et* *al*. 1986). Because ALKA covers a large linear coastal transect along West Hawaii, the rainfall pattern is variable.

The climate of Guam and the Northern Marianas (CNMI), including Saipan, is warm, wet, and tropical. Temperature varies between 90 and 70° F. Relative humidity is high, often exceeding 80% and seldom falling below 50%. The rainfall pattern is strongly seasonal with a wet season from July to November and a pronounced dry season from December to June. Average annual rainfall of the Marianas is 2,160 mm (85 in) (Baker 1951), and on Guam the annual mean is 2,175 mm (Mueller-Dombois and Fosberg 1998). Typhoons are yearly events, which occur during the monsoonal wet season. Trade winds blow from the northeast, but easterly and southeasterly winds prevail during several months in the spring (Baker 1951). Because Guam and the Marianas are relatively low islands, there is no pronounced rain shadow effect, and leeward shores are not drier than those of the windward sides (Mueller-Dombois and Fosberg 1998).

NPSA has a warm tropical climate with little seasonal variation in temperature. Rainfall is high in the four units of the park. On Tutuila, annual rainfall averages 3,200 mm (at the airport), and may be even higher on the upper mountain slopes within the park. Rainfall is seasonal with greater monthly means from October to May and a dry season from June to September. Hurricanes are occasional but not annual events (Whistler 1994). Tau Island unit is only about 96 km (60 miles) east of Tutuila and shares its warm and wet tropical climate. Tau average rainfall is more than 2,500 mm per year and is highest in December. The dry season is June to September, and droughts sometimes occur on the island (Whistler, 1992).

CONCEPTUAL ECOLOGICAL MODELS

The air quality and climate conceptual model focuses on the dominant drivers, stressors, and ecological effects that have been identified for the PACN region. Many of the issues were first discussed for the region as whole in a workshop held in November 2001 in conjunction with the annual PRIMENet (Park Research and Intensive Monitoring of Ecosystems Network) meetings at Hawaii Volcanoes National Park. The three overarching categories or drivers that were identified are air quality, climate and climate change and extreme events. Each one of these drivers incorporates a variety of resource stressors in PACN national parks.

DRIVERS AND STRESSORS

Air Quality

Air Quality conditions determine the delivery of nutrients and pollutants via wet and dry deposition. In this way air quality can have a profound influence on nutrient cycling and thus ecosystem processes. In general, air quality in the PACN is good. Concentrations of pollutants are well below National Ambient Air Quality Standards (NAAQS) established by the EPA to protect human health and the environment. However, under certain weather conditions volcanic emissions or fires can lead to localized deterioration of air quality.

Distribution of atmospheric pollutants in the PACN is controlled by global as well as regional circulation patterns. On a large scale, slow mixing of tropospheric air between the two hemispheres results in an interhemispheric gradient in CO_2 mixing ratios as can be seen in data (http://www.cmdl.noaa.gov/ccgg/insitu.html) from NOAA CMDL observatories in Hawaii and

American Samoa. Mixing ratios are higher in the northern hemisphere where most of the carbon fuels are burned.

Atmospheric deposition of pollutants from anthropogenic sources in the PACN is relatively low compared to continental North America, due to the isolation of the islands. WAPA and AMME may receive more pollution from a continent than the other parks due to the proximity to continental Asia. However, no air quality monitoring is conducted at Guam and CNMI to determine the influence of pollution plumes from the Asian continent. Despite the geographic isolation, continental pollution plumes have been recorded in aerosol samples at observatories in American Samoa and Hawaii.

Within the PACN region volcanic activity is probably the largest ‘point’ source for atmospheric gases and particles. Occasionally, depending on wind and eruption conditions, emissions from Anatahan, an active volcano located 120 km north of Saipan, reach Saipan and Guam. In Hawaii volcanic emissions are a constant pollution source and, at times, lead to a severe deterioration of air quality. Distribution of the volcanic plume from Kilauea volcano on the island of Hawaii depends on current weather conditions. Under steady trade wind conditions the plume is blown offshore and southwest and air quality conditions close to the source remain good. However, the plume worsens air quality conditions on the leeward side of the island. Two tall mountains, Mauna Loa (4200 m) and Hualalai (2500 m) shelter the leeward or Kona side from the trade winds. As a result, the differential heating of land and sea surface leads to the production of sea breezes during the day and land breezes at night and volcanic emissions get trapped in the onshore-offshore movement of the air. The presence and intensity of the trade winds is affected by the position of the subtropical high pressure area. In the summer this high pressure area lies well north of the islands and trade winds are steady. In the winter the axis or ridge of the high pressure area moves close to the islands and the trade winds often die down (Schroeder 1993). Under those conditions Kona experiences clear air while the air quality conditions around Kilauea deteriorate significantly due to the slow spreading of the highly concentrated plume.

El Niño Southern Oscillation (ENSO) also influences air quality conditions within the PACN area. For instance, during the ENSO event of 1997-98 air quality deteriorated in Guam and Micronesia due to increased numbers of local wildfires as well as due to haze from wildfires burning in Indonesia (Shea et al. 2001). The prolonged change in the prevailing wind conditions during El Niño can lead to extended periods with poor air quality.

Across the PACN increasing urbanization is affecting air quality conditions, due to increased emissions from vehicles as well as from power plants, small industrial businesses and waste incinerators. The pollution can be in the form of toxicant emissions or unpleasant odor as in the case of emissions from a Tuna cannery in Pago Pago, American Samoa. In some cases NAAQS were exceeded. For instance, in the areas in a 3.5 km radius around the two Guam power plants SO_2 levels are routinely exceeded (EPA 2004). Furthermore, two medical waste incinerators on Guam were closed (EPA 2004b) due to violations of emission standards set by the Clean Air Act.

Some practices in rural areas also lead to occasional and localized air pollution. For instance, the burning of trash is still a common practice on all the islands in the PACN. In addition, in American Samoa the burning of vegetation to clear plots for subsistence agriculture causes air pollution (NPS 1997). This kind of localized, occasional air pollution is often not monitored in the PACN and is generally not considered a threat. Conditions tend to clear quickly as emissions are blown out to sea with the prevailing trade winds.

Climate

Analyses of ecosystem development and processes are based on the ideas of Jenny (1941, 1980) who identified five 'state factors' that determine how systems evolve, differ from each other and vary from one landscape to another. Climate is one of these state factors or major ecosystem drivers; the others are organisms, topography, parent material and time. Some information about the climate in the PACN was already provided in the ecological context section. Here some more detail is provided on important factors shaping the climate zones and ecosystems in the islands.

The climate in the PACN region is often described as mild, referring to relatively warm temperatures and minimal daily and seasonal temperature fluctuations. Moderate wet and dry seasons exist throughout the region, yet these seasons are not synchronous. For example, in American Samoa the wet season lasts from October to May, in the Marianas from July to November, in most of Hawaii from October to April, while in some portions of leeward Hawaii (i.e. North Kona) it lasts from April to September.

The dominant factor shaping the climate is the tropical marine setting (Fig1.). The vast Pacific Ocean dampens the temperature fluctuations and leads to a constant high relative humidity. Located between 15°S and 21°N the climate is influenced by the Hadley cell (Fig.2), which describes the global circulation pattern in these latitudes. Warm, moist tropical air rises near the equator (the doldrums), moves poleward and, as it cools, sinks back to the surface at around 30° north and south. At the surface the air moves from the subtropical high pressure center back toward the equatorial trough. As a result of the Coriolis force these air masses are deflected, such that the northern and southern hemispheres experience persistent NE and SE trade winds respectively.

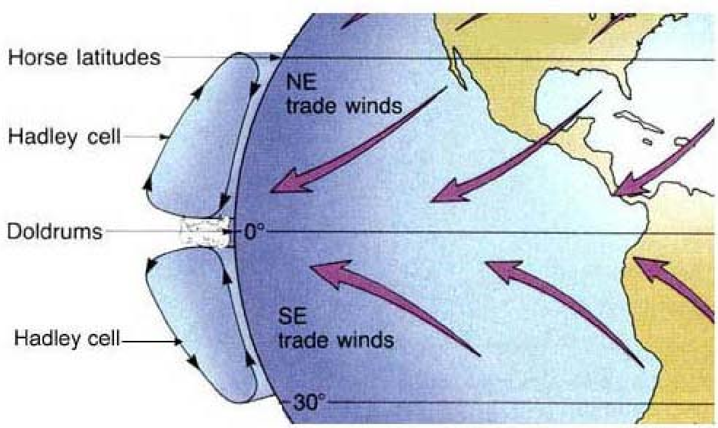

Figure 2. Hadley Cell Circulation and the Trade Winds

A characteristic feature of the Hadley cell is the trade wind inversion. Subsiding air in the Hadley cell warms as a result of compression. At the same time, air rising from the surface cools. At the meeting point of the two air masses warm air overlays cool air forming an inversion. The presence of the trade wind inversion is an important factor influencing PACN ecology as it creates distinct zones along elevation gradients on the taller islands. Orographic uplift of moist air masses is capped by the warmer overlying air leading to the formation of a persistent cloud belt just below the inversion supporting cloud and rain forest habitat. Additionally, the interaction of the trade winds and the relief create wet windward and dry leeward climate zones. Thus, despite the tropical setting, the parks in the PACN encompass nearly all of the world's major climate types as defined by Koeppen (Giambelluca and Sanderson 1993), sometimes within a single park (HAVO, HALE).

Table 1. Summary matrix: Geography of Atmospheric Systems and PACN Parks

Elevation	N. Hemisphere Volcanic influence	N. Hemisphere No Volcanic Influence	S. Hemisphere No Volcanic Influence
Above inversion	HAVO	HALE	
Below inversion in cloud	HAVO	HALE, KALA	NPSA
Below inversion below cloud	HAVO, PUHE, PUHO, KAHO, ALKA	HALE, KALA, USAR, AMME, WAPA	NPSA

Climate variability for the region is often described in terms of the Pacific Decadal Oscillation (PDO) and the El Niño/Southern Oscillation (ENSO). These are naturally occurring phenomena that are defined by atmospheric and oceanic conditions in the Pacific Ocean but affect climatic and oceanic conditions around the globe. An El Niño phase is characterized by unusually warm waters over the eastern and central tropical Pacific (Fig 3 – modified from NOAA CPC). The opposite is true during La Niña; sea surface temperatures in the region are cooler than normal. El Niño and La Niña events often but not always follow each other and each typically lasts for a year to 18 months. El Niño events recur every 3-7 years.

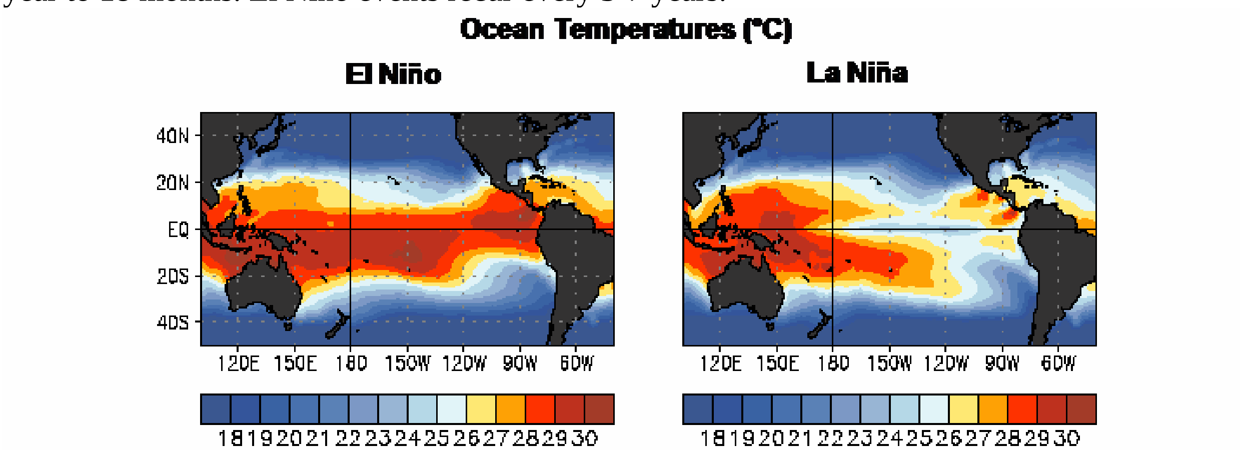

Figure 3. El Niño and La Niña Pacific Ocean Temperatures

The Southern Oscillation, or SO, refers to the difference in atmospheric pressure at sea level between the eastern and western tropical Pacific. During El Niño the pressure tends to be lower than average in the eastern Pacific and higher than average in the western Pacific. During La Niña the pattern is reversed. The standard measure is the pressure difference between Tahiti, French Polynesia and Darwin, Australia. The effects of ENSO are especially noticeable in the Pacific but also impact weather patterns in other parts of the world. ENSO events are associated with changes in sea level, wind patterns and rainfall regimes. Though, even across the Pacific the changes are not uniform, some areas experience drought others receive excessive rain.

Similar to ENSO, the Pacific Decadal Oscillation is also marked by changes in sea surface temperatures and atmospheric pressures. During a 'negative' PDO phase SSTs and sea level pressures are lower than average in the eastern equatorial Pacific and higher than average in the north, west and southern Pacific. The reverse is true during 'positive' PDO phases. What distinguishes PDO from El Niño is that it persists on a timescale of decades (20-30 years) rather than months and that its climatic effects are primarily felt in North America and less in the tropics; the opposite is true for ENSO (Mantua 2000).

Climate Change

Global climate change is a natural phenomenon as paleontological records show. However, human-induced global climate change is expected to include much more rapid rates of change in climate parameters than have been experienced for millennia (Kennedy et al., 2002). Marine and coastal, and in particular small island ecosystems are considered to be especially vulnerable to rapid climate change (Carter et al. 2001, Hay et al. 2001). Throughout the Pacific changes in several climate and climate related parameters over the last few decades are attributed to anthropogenic climate change. These include temperature, precipitation, sea-surface temperature, and sea-level. Some of these changes have already negatively impacted ecosystems. For instance, increases in sea surface temperatures have been linked to coral bleaching. A more detailed discussion of observed or expected changes in climate parameters and the impending threats to ecosystems follows below in the section on park and network-wide issues.

Extreme Events

Extreme events or disturbances both affect and are indicative of climate and air quality conditions. Examples of such events range from topical cyclones, storm waves, flash flooding, extended drought conditions or even extended wind or cloud free conditions, such as those that result in periods of significant air quality deterioration, to fires and volcanic eruptions. Often, extreme events are part of the natural conditions of the area. For instance, volcanic eruptions, fires resulting from volcanic activity or storm waves and flooding resulting from tropical cyclones are recurring events due to the geological and climatic setting. However, many scientists expect that anthropogenic climate change will affect the frequency and/or intensity of extreme weather events in the Pacific (Carter et al. 2001, Hay et al. 2001).

Extreme events have severe, wide ranging and often long lasting effects on ecosystems. Furthermore, management of visitor behavior for safety during such events is of extreme importance, whether it involves evacuating an area during a tropical cyclone or managing crowds watching high surf.

ECOSYSTEM RESPONSES

Atmospheric deposition is influenced by volcanic emissions, long range transport of pollutants and dust, local dust events, fires and local or regional emissions of air toxics. Changes in nutrient deposition loads (especially C, N, P, K+, Mg2+, Ca2+) and deposition of toxics such as POPs and heavy metals affect all aspects of ecosystem functions. Impacts include direct toxic effects to flora and fauna, facilitation of alien species invasions, changes to biogeochemical cycles, changes to species composition, destruction of unique habitats, etc. Besides these effects, global air pollution by long lasting chemical species such as CO_2 or other green house gases is also affecting ecosystems by inducing regional or global climate change.

The effects of climate change are just as wide ranging affecting ecosystems on all levels. Specific effects that are of concern within the PACN include coral bleaching due to increased levels of UV radiation and increased sea temperatures, as well as habitat changes affecting sensitive cloud forest due to increased droughts.

Extreme events have severe impacts on ecosystems and recovery time is long. Sometimes the destruction is so severe that a return to original conditions will not occur unless restoration efforts are implemented.

Both, abiotic and biotic characteristics of ecosystems are directly affected by the stressors. Additionally, there are indirect effects through the interaction between the ecosystem attributes. For example, for cloud and rain forest habitat, long-term changes in cloudiness and precipitation will directly affect the hydrological cycle which will then affect community structure and biodiversity. In addition, there are numerous interactions between the drivers/stressors, such as increasing CO_2 (anthropogenic emissions) leading to climate change, which in turn affects the occurrence of extreme events. The Air-Quality-and-Climate-Ecological Conceptual-Model (Fig. 4) illustrates the relationships between the drivers, stressors and the affected ecosystem attributes.

Ecological Conceptual Model

Figure 4. Air Quality and Climate Ecological Conceptual Model

In this model, blue rectangles represent drivers, red ovals are stressors, and green octagons are affected ecosystem attributes. The goal of the PACN monitoring plan is to select a set of vital signs for long term monitoring. The term 'vital signs', as used by NPS, refers to a subset of physical, chemical and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of the park resources, known or hypothesized effects of stressors, or elements that have important human values" (NPS 2003b). In the above model vital signs, relating to air quality and climate, that may be identified as or selected for monitoring appear as stressors. There are numerous interactions between the main drivers, the stressors and the attributes as indicated by the arrows. The stressors often affect each other and, thus, the term 'atmospheric chemical and physical conditions', which encompasses air quality and climate conditions, appears under abiotic attributes.

PARK AND NETWORK-WIDE ISSUES

VOLCANIC EMISSIONS

Volcanic emissions are of major concern at HAVO, with other parks on the island of Hawaii (PUHO, KAHO, PUHE, & ALKA) affected as well. Parks on other islands in Hawaii are affected to a lesser extent. Volcanic emissions from Kilauea present a long-term source of pollutants. Kilauea volcano has continuously erupted since 1983, thereby emitting large amounts of gases and aerosols. Volcanoes in American Samoa are not considered extinct, but eruptions are not an immediate concern. The most recent eruptions took place in the early part of the 20^{th} century on Savaii (Western Samoa) and a submarine eruption took place between Ofu and Olosega in 1866. Concern at WAPA and AMME is episodic, in conjunction with active eruptions of Anatahan north of Saipan. Explosive eruptions of Anatahan have resulted in ash fall on Saipan and Guam. Saipan residents have also reported a rotten egg smell indicative of H_2S emissions during these events (USGS 2003).

The effects of air quality changes due to volcanic emissions are wide ranging and include:

- Haze - plumes of vog (volcanic smog) which significantly reduce visibility.
- Changes to weather patterns; emission of large amounts of fine aerosols which can alter precipitation patterns and attenuate light.
- Human health effects, primarily respiratory problems. Both short term exposure to extreme vog or laze (lava haze) plumes and long-term exposure to less extreme conditions are of significant concern.
- Materials effects - the corrosive (acidic) nature of the volcanic fumes affects metal, wood and synthetic building material requiring frequent maintenance and replacement of interpretive signs, boardwalks, building paints and roofing.
- Vegetation effects – the acidic nature of the emissions leads to severe damage of leaves.
- Changes in wet, occult and dry deposition loads. Of particularly concern are increases in sulfur compounds which lead to acidification of soils and increased uptake of plant toxins such as aluminum.

Vog/SO_2/Aerosols

Depending on volcanic activity and wind conditions vog can seriously degrade air quality at HAVO, PUHO, KAHO, PUHE and ALKA. Vog is a mixture of SO_2 gas, acidic particles and trace amounts of toxic metals (USGS 1997). Near Kilauea SO_2 is the major component of vog, but along the Kona coast aerosol particles dominate. The largest particles in vog are about 1.7 mm but mostly they are submicron in size (Clarke 1996, Chuan 1997).

Annual reports for Hawaii air quality from the Department of Health (DOH 2000-02) show that, in general, Hawaii air is very clean and pollutant concentrations are well below federal and state standards set to protect human health. However, between 1987 and 1997 the 24 hour and 3 hour

NAAQSs (National Ambient Air Quality Standards) were exceeded 3 to 20 times annually at HAVO (Ray 1998). During these episodes of severe, though very localized deterioration of air quality negative health effects are likely. An alert system has been implemented at HAVO to protect visitors and employees from adverse health effects due to high SO_2/aerosol concentrations. Data of SO_2 concentrations from two monitoring stations within the park are transmitted to a computer at the dispatch office every 15 minutes. Air quality conditions are evaluated as good (SO_2 concentrations below 300 ppb), moderate (300-499 ppb), unhealthy for sensitive people (500-1000 ppb) or unhealthy for everyone (>1000 ppb). Depending on the degree of air quality degradation various safety measures are taken such as closing visitor center doors and windows, canceling outdoor work and hikes, or temporarily closing the entrance station and visitor centers. The HAVO SO_2 alert system has an online display at http://www2.nature.nps.gov/air/WebCams/parks/havoso2alert/havoalert.htm.

Local residents attribute a wide variety of physical symptoms to vog exposure, but no long term scientific studies have been conducted. Several studies to assess the health effects of vog have been initiated by the University of Hawaii (UH Hilo, Chemistry and UH Manoa School of Medicine) and the Hawaii Department of Health (DOH). Results indicate that vog may be a factor for some respiratory illnesses but other factors, for instance mold, appear to play a role (Michaud et al. 2004). Further studies are needed to determine the impact of vog on human health.

Detrimental effects on human health and the environment of the individual components of vog are well known. Particulate matter below 2.5 mm is able to penetrate to the deepest parts of the lungs. Scientific studies have suggested links between fine particulate matter and numerous health problems including asthma, bronchitis, acute and chronic respiratory symptoms such as shortness of breath and painful breathing, and premature deaths (EPA 2003). SO_2 is a severe irritant to the skin, eyes and the mucous membranes of the nose and upper respiratory tract (ATSDR 2001).

Adverse effects of SO_2 on vegetation have been reported in many studies. While some native Hawaiian plants have evolved SO_2 resistance, at least for mature stages, many native as well as introduced species are sensitive to SO_2 exposure (Winner and Mooney 1985). Uptake of SO_2 via stomata leads to foliar injury.

Significantly increased sulfur concentrations in precipitation, cloud water, and atmospheric gases due to vog episodes are well documented (Heath 1996 2001, CASTNET 1999-2003). This indicates that volcanic emissions may have a profound impact on biogeochemical cycling in affected areas. For instance, acidification of soils can lead to increased uptake of Aluminum and Hydrogen ions which are plant toxicants.

Monitoring of SO_2 in Hawaii provides a unique opportunity to examine the ecological effects of a single pollutant rather than a suite of contaminants as in the case of pollution in urban areas.

Hydrogen Sulfide

Volcanoes are a natural source of hydrogen sulfide (H_2S), a highly toxic gas. However, studies at several sites on Kilauea have shown that concentrations are low and pose no threat to human health (Sutton et al. 1994). Furthermore, due to the abundance of SO_2, H_2S is rapidly converted to elemental sulfur and water diminishing the risks to human health (Sutton and Elias 1993).

Accidental releases of H_2S from a geothermal power facility in close proximity to HAVO have been recorded.

Laze

Laze is a mixture of hydrochloric acid and concentrated seawater resulting from the interaction of lava with the ocean. Laze plumes are a localized health hazard for visitors at coastal areas where molten lava enters the ocean (HAVO). The highly acidic plume affects the respiratory system and can also lead to irritation of the skin and mucous membranes of the eyes and nose. Acid burn of nearby vegetation can also be observed.

Mercury

Elevated atmospheric mercury levels resulting from volcanic emissions have been found as far away as Oahu over 300 km from the source (Siegel and Siegel, 1984). Elevated levels in soil and plant samples are highest on the island of Hawaii, particularly in close proximity to steam vents (Davies and Notcutt 1996), but coastal sediments on Oahu also show the influence of the volcano (McMurtry et al. 1995, Raine et al. 1995).

"A comparison of recently measured mercury values with published environmental health standards suggested that potentially hazardous air concentrations may exist in the Hawaii Volcanoes National Park and the lower portions of the adjacent Puna District." (Siegel and Siegel 1978). Due to elevated levels of mercury in ocean fish the Hawaii DOH has issued health advisories for at risk groups (i.e., small children, pregnant women and nursing mothers). However, no studies have been conducted to determine whether there is a link between the mercury levels in ocean fish and volcanic emissions (Barbara Brooks, Hawaii DOH pers. comm.).

Mercury pollution also affects vegetation. Based on a study of mercury emissions from volcanoes on the island of Hawaii Siegel and Siegel (1987) state that, "It has been found that seedlings have a 300-fold greater sensitivity to mercury than mature plants, which respond by premature senescence."

See also discussion of mercury in the following section.

ANTHROPOGENIC POLLUTANTS

Effects of Hazardous Air Pollutants (HAPs) on human health include, "cancer, neurological, cardiovascular, and respiratory effects, effects on the liver, kidney, immune system, and reproductive system, and effects on fetal and child development" (EPA, 2000). The effects may be the result of immediate toxic effects or due to bioaccumulation. HAPs also pose a threat to terrestrial and marine ecosystems. Impacts on the health of fauna are generally similar to health effects experienced by humans. Vegetation too, is often affected by acidity or toxicity of HAPs. Extensive documentation of impacts on marine and fresh water bodies have resulted in increased legislation to protect water quality. In the PACN region the EPA does not monitor air pollution by HAPs or PBTs (Persistent, Bioaccumulative and Toxic Chemicals) on a regular basis, but only in response to emergencies. However, legislation requires certain facilities manufacturing, processing, or otherwise using listed toxic chemicals to report the annual quantity of such chemicals entering each environmental medium. Many of these chemicals are very volatile and soluble and pollution is often detected in water quality testing rather than in air quality monitoring (see also the Water Quality, a supporting document to the PACN Monitoring Plan).

Mercury

Hawaii ranked forty-eighth in a state by state comparison in total mercury emissions from industry and military facilities. According to the EPA's Toxic Release Inventories no emissions were reported from other Pacific Islands in the PACN (EPA 2003b). However, mercury contamination of harbor sediments resulting from activities of adjacent military bases has been reported on Guam (GEPA 2000). In Hawaii increased levels of mercury resulting from volcanic emissions have been found in ambient air, plants and sediments (Siegel and Siegel 1978, 1984, 1987, McMurtry et al. 1995). Fish contaminated with mercury- and organochlorides- due to pollution resulting from human activities have been found in KAHO fishponds. The USGS is investigating pollution levels and ecosystem effects (http://hi.water.usgs.gov/projects/project_kaloko.htm).

Air emissions are the primary source of mercury entering the environment (EPA 2003c). Despite the fact that current levels of mercury in the atmosphere exceed pre-industrial levels by three to six times ambient levels are generally still so low that they do not constitute a public health risk (ATSDR 2001). However, volcanic emissions in Hawaii may increase levels in parts of HAVO enough to endanger humans (Siegel and Siegel 1978). Furthermore air emissions are responsible for contamination of terrestrial and marine ecosystems. In an aquatic environment mercury transforms into its most toxic form, methylmercury. In that form it bioaccumulates in fish and poses threats to fish populations as well as humans. Methylmercury is almost completely absorbed into the blood stream and distributed to all tissues including the brain. It can also easily pass through the placenta to a fetus.

Mercury levels in fish are addressed in health advisories by federal and state agencies. The FDA recommends that pregnant women, those who may be pregnant, and children under five should not eat predatory fish species. All the parks in the PACN are located on islands and most of them include marine habitat. Thus, mercury contamination and consequent impacts on marine fauna are of concern, as are impacts on human health since fish is a major part of the diet of island populations. According to the US Public Interest Research Group (US PIRG), Hawaii is among the states that conduct none or very limited monitoring for mercury (US-PIRG 1999). The DOH has only recently issued a fish consumption advisory for small children, pregnant women and nursing mothers (DOH, 2003). American Samoa also issues health advisories for high concentrations of mercury in fish. At this time we don't have information about whether Guam and Saipan issue mercury advisories.

Radioactive Materials

Airborne releases of radioactive materials are a possibility at Pearl Harbor given the active use of radioactive materials on US Military installations. Environmental monitoring in the area is conducted by the military. However, these monitoring efforts do not include routine monitoring of air quality. Presumably USAR would respond under the direction of the military and the department of Civil Defense in the event of contamination.

Sulfur

Concerns regarding air quality degradation due to sulfur emissions from volcanoes are described in a previous section (A2-Volcanic Emissions, Vog/SO_2/Aerosols). The major anthropogenic source of sulfur, mainly in the form of SO_2, is emissions from power plants. SO_2 is of concern as a source of particulate matter and because it is the main precursor for acid rain. The EPA has exempted Guam, American Samoa and Saipan from the sulfur dioxide emission requirements as stated in the Clean Air Act. This exemption allows power plants on Guam, Tutuila and Saipan to use higher sulfur fuels, but requires Guam and Samoa EPA and the department of environmental quality (DEQ) on Saipan to monitor SO_2 emissions. There is some discrepancy regarding information about SO_2 monitoring in Guam. Upon our inquiries to the Guam EPA we were told that no air quality monitoring of any sort is taking place except in emergency situations. However, the areas within a 3.5 km radius around the Piti and Tanguisson power plants on Guam were classified as non-attainment areas by the EPA as of May 2004 (EPA, 2004) indicating that some monitoring is taking place. Non-attainment areas are defined as areas of the country where air pollution levels persistently exceed NAAQSs. The ASEPA and Saipan DEQ are not conducting any air quality monitoring at this time. Effects of SO_2 on human health and the environment are listed under the section on Volcanic Emissions, Vog/SO_2/Aerosols.

Particulate Matter

Particulate matter (PM) refers to a mixture of solid particles and liquid droplets found in the air. If PM is in the size range between 10 and 2.5 μm it is called PM 10 if the particles are smaller than 2.5 m it is called PM2.5. Sources include fuel combustion from automobiles, power plants, wood burning and industrial processes, or from gas-to-particle conversion of gaseous pollutants. PM presents a risk to both human health and the environment. Respiratory illnesses are the main concern for humans and animals. Visibility impairment and acid rain are the main environmental concerns. In the PACN the main source of PM is volcanic emissions, but rubbish and landfill burns and other fires lead to localized air quality deterioration that is generally not monitored, but often noticeable in PACN parks. At KAHO there is also concern about air quality degradation due to dust plumes from two nearby quarries.

Carbon Dioxide

Carbon dioxide (CO_2) concentrations are rising as a result of anthropogenic emissions. Due to the long lifetime of CO_2 this increase is also noted in remote locations as data from the NOAA CMDL observatories in Hawaii and American Samoa show (Keeling 2004). The main focus tends to be on the role of CO_2 as a greenhouse gas and the effects of the resulting climate change. However, increasing levels of CO_2 also have more direct effect on ecosystems due to increased carbon sequestration. This is discussed in more detail in the 'nutrient cycling' section below.

Ozone

Tropospheric ozone is a major pollutant that is present not only in urban areas but also in many US national parks, causing serious plant damage and concerns for human health. The EPA NAAQS (National Ambient Air Quality Standard) primary standard, for protection of human health, is 0.080 ppm for an 8-hour average. The secondary standard, for protection of the environment, was lowered in July 1997 and is now identical to the primary standard. In the PACN region ground level ozone concentrations are far below this level. Data from the

CASTNET (Clean Air Status and Trends Network) site at HAVO show 8-hr averages varying between 0.01 and 0.03 ppm (CASTNET 1999-2003) and NOAA CMDL data show even lower values for the American Samoa observatory which is located on Tutuila in close proximity to NPSA. Increases in tropospheric ozone, due to anthropogenic precursor emissions, took place mainly in the 1970s and early 1980s, but rates of increase were much lower at Mauna Loa than at European stations and no increase was noted at American Samoa (Oltmans et al. 1998).

FIRE & HAZE

Fires may have natural causes (i.e., ignition by lava or lightning) or are the result of human activity. They may be set intentionally - arson, landfill burns- or unintentionally such as out of hand prescribed burns or campfires. Effects can be felt locally or regionally, depending on size of the area burned, duration, and fuel load and type. Depending on the fuel type, fires in urban/industrial areas may increase air toxics concentrations. “Large area or long lasting biomass burning releases large quantities of reactive compounds to the atmosphere, in particular NOx, hydrocarbons and CO. Large quantities of soot and organic carbon are also emitted” (BIBEX 2003). In general, fire results in increased gaseous and particulate matter (PM 2.5) in the atmosphere with similar effects as volcanic emissions including human health effects, particularly respiratory problems, haze causing poor visibility, and changes in deposition loads. Smoke and haze from large forest fires has also been found to reduce photosynthesis both indirectly through reduced PAR (Photosynthetically Active Radiation) levels, and directly through elevated aerosol and atmospheric pollutant levels (Davies & Unam 1999). State Implementation plans are primary means of addressing regional haze, with a focus on Class I areas, which are afforded special protection under the Clean Air Act. Within NPS haze and other air quality problems related to fires are often addressed in Fire Management Plans.

While all of the parks to some extent are subject to fires, some parks are more affected than others. As a result of active lava flows HAVO experiences frequent and sometimes long-lasting biomass burning. Lava ignites 95% of fires at HAVO, 5% are caused by humans. Spatial extent and duration vary, with some of the fires persisting for extremely long times. For example, a fire ignited by lava on Mother’s Day 2002 lasted for 15 months and burned 10,000 acres. No special devices are set up at HAVO to monitor changes in air quality during fire episodes. However ash fall and poor air quality have led to road closures.

Fires resulting from arson, set to facilitate hunting, are a significant problem on Guam, where over 700 fires are set per year. WAPA experiences 5 to 10 fires a year. It is estimated that 20% of the island and the national park burn each year (Minton 2004). The chain reaction of fire, consequent erosion due to heavy rains and resulting coral reef demise due to heavy sedimentation is being actively studied at WAPA. However, the changes in air quality, deposition loads, trace gas emissions/sinks due to the fires are not investigated.

The 1997-98 El Niño drought conditions also reduced local air quality conditions due to increased wildfires on Guam, as well as some other Pacific Islands. In addition, during that El Niño season haze from Indonesian forest fires impacted air quality on Guam (Shea et al. 2001).

LONG-RANGE TRANSPORT OF AEROSOLS

Pollutants

The southern hemisphere has significantly less land mass than the northern hemisphere, thus less anthropogenic emissions and generally lower concentrations of pollutants. However, even the remote South Pacific is not as pristine as it once was. Significant industrial growth in Asia and biomass burning in Africa and South America has resulted in pollution plumes reaching this area (Sing et al. 2000). Remote locations in the northern hemisphere are also subject to pollution plumes. Smoke from the south west U.S. mainland and from Asia has been detected at Mauna Loa Observatory (Mims and Mims 2004). Indonesian forest fires have reduced air quality on Guam, Yap, Pohnpei and Palau (Shea et al. 2001). Outflow of pollution plumes from the Asian continent also contribute significantly (23-44%) to CO mixing ratios in many sites in the north Pacific, including sites at Midway, Hawaii and Guam (Liang et al. 2004). Carbon monoxide is commonly used as a tracer of anthropogenic emissions and the results of this study suggest that concentrations of other pollutants may also be elevated. As industrialization and thus burning of fossil fuels increases on the Asian continent, it can be expected that the influence of the Asian outflow on pollutant concentrations in the north Pacific will increase as well.

Potential environmental impacts are diverse and include acid rain, an increase of cloud condensation nuclei leading to changes in cloud formation and precipitation patterns and production of tropospheric ozone (Sing et al. 2000). The presence of fungal spores and bacteria transported in smoke from distant biomass fires are an additional concern. For example, at Mauna Loa Observatory spores have been found in smoke from an Arizona forest fire and from biomass fires in Asia (Mims & Mims, 2004). Viable spores and bacteria can spread plant diseases and may cause allergic reactions in humans.

Mineral Dust

At HAVO deposition of Asian dust (i.e., a spring peak in Ca concentrations) has been noted in dry deposition studies (Heath 2001). Asian dust deposition has also been noted in IMPROVE (Interagency Monitoring of Protected Visual Environments) aerosol samples at the NOAA CMDL Mauna Loa Observatory station.

EPA standards for particulate loads are generally based on studies evaluating human health effects of high concentration of pollutants stemming from anthropogenic sources. Some recent studies suggest that the chemical characteristics of mineral dust could result in cardiopulmonary toxicity even in the low concentrations conditions seen after long range transport (Prospero 1999) but further research is needed.

Ecosystem effects of Asian dust accumulation can be significant. Soil profile studies have revealed that despite the fact that Hawaii is remote from continental dust sources and addition is very gradual, over "tens to hundreds of thousands of years, accumulation of Asian dust in these soils begins to have a considerable impact on soil nutrient budgets and on bulk soil mineralogy and geochemistry" (Kurtz 2001).

CLIMATE & CLIMATE CHANGE

Determining whether changes in climate are part of the natural variability of the region or due to anthropogenic climate change requires analysis of a time series. For infrequent phenomena such as Pacific Decadal Oscillation (PDO) and EL Niño Southern Oscillation (ENSO) analyses of decades of data are insufficient and paleontological records need to be taken into account. Long-term datasets of meteorological parameters are required to distinguish between base-line versus disturbed conditions and to establish cause and ecological effect relationships. Studying the effects of short-term climate variability such as experienced with La Niña/El Niño conditions may lead to insights about environmental impacts that can be expected with long-term climate change.

El Niño Southern Oscillation (ENSO) / Pacific Decadal Oscillation (PDO)

Both of these phenomena are characterized by patterns of Sea surface temperature and atmospheric pressures in the Pacific (see also the Climate section under Drivers and Stressors). The PEAC (Pacific ENSO Applications Center) conducts research and distributes information and educational materials about ENSO events. In response many governments of the Pacific developed El Niño task forces that serve to educate the public about mitigation of harmful consequences from El Niño related changes in weather. Climatic consequences of ENSO are much more pronounced in the Pacific region than on the North American continent and the rest of the world, while the climatic fingerprint of PDO affects primarily the North American continent and has only secondary effects in the Pacific. Climatic changes resulting from ENSO are dependent on the pattern of SST and thus vary throughout the Pacific. However, the following effects of El Niño are common to the PACN region:

- Changes to wind patterns: The trade winds weaken, die down entirely and the wind may even completely change direction blowing towards the east.
- Increased sea surface temperature: Change in wind strength and direction allows the western Pacific warm pool to expand eastward; the larger the warm pool the stronger the El Niño tends to be.
- Rise in sea level: Due to the increased volume of water and thermal expansion sea level tends to rise.
- Increased tropical cyclone frequency and intensity: Warm waters are one of the prerequisites for the formation of tropical cyclones. In the Pacific El Niño events increase the area of origin and expand the season for tropical cyclones.
- Increased flood frequency and intensity: The increase in tropical cyclone frequency and intensity also affects flooding.
- Extended drought conditions: Although flood events increase as a result of storm events overall precipitation is decreased to the point of causing serious drought damage.

La Niña events affect the above named parameters in the opposite way. Ecological consequences of these changes are discussed under individual headings below.

Extreme Events

Extreme events are often associated with El Niño Southern Oscillation, thus they are natural occurrences. However, if as currently predicted, human-induced climate change leads to altered disturbance regimes, such as increased frequency and/or intensity of severe wind storms, droughts or floods it will also lead to more severe damage and give ecosystems less time for recovery.

Tropical Cyclones

In the PACN tropical cyclones with maximum sustained winds of 63 knots per hour or greater are called hurricanes in Hawaii, severe tropical cyclones in American Samoa, and typhoons in Guam and the CNMI. In this report the term tropical cyclone will be used regardless of the geographic region referred to. During El Niño years the frequency and intensity of tropical cyclones tends to increase in the Pacific, during La Niña years frequency and intensity are decreased. American Samoa tends to not be affected by tropical cyclones except during El Niño events (Shea et al. 2001). There is no consensus among scientists on whether frequency of cyclones in the tropical Pacific will increase in a warmer world even during non El Niño years. Both, increases and decreases in frequency have been suggested in a number of studies reviewed by the IPCC (IPCC 2001). However, there seems to be agreement that an increase in global CO_2 levels and associated rise in temperatures would lead to an increase in the intensity of storms.

The destructive forces of tropical cyclones include storm surge, winds, salt stress, and heavy rainfall/flooding. Storm surge is defined as the difference between the mean tide level and the tide level during the storm. It is often the most destructive force of a tropical cyclone. The weight of the water - one cubic meter of water weighs one ton - combined with its moving force will destroy structures, uproot even mature trees, and can significantly change shoreline features. Wind stress and salt stress often kill vegetation or lead to extensive defoliation. It has been observed that during some tropical cyclones more that the average annual litterfall occurred (Lodge and McDowell 1991). Defoliation affects terrestrial ecosystems in several ways; the opening of the canopy changes light conditions, leaf litter provides an excessive pulse of nutrients, and loss of foliage decreases gas exchange capacity of the surviving vegetation. As a result forest succession is affected and the spread of alien species is often facilitated.

Following tropical cyclones changes to trace gas fluxes, soil structure and fine root mass have also been observed (Herbert et al. 1999, Ostertag et al. 2003). Tropical cyclones also affect marine ecosystems. Coral reefs support a high diversity of plants and animals and protect the coast from wave and wind damage. However, they can not withstand storm waves created by Tropical cyclones. The forces of the initial tropical cyclone and the loss of protection from further storms lead to long lasting problems with erosion and sedimentation with further damage to the shoreline and reefs (Kennedy et al. 2002). Coral reefs near all the islands in the PACN have sustained damage due tropical cyclones in the 1980s and 1990s.

Floods

Flooding can occur as a result of storm waves or excessive rain associated with a tropical cyclone or other storm systems. It must be noted that periods of strong rainfall are a characteristic of this region and a certain amount of flooding is needed to recharge the freshwater lens. Tropical cyclones that pass by the islands without causing extensive wind and wave damage, but deliver strong rain serve the important purpose of recharging the freshwater lenses. Reduced groundwater levels have been noted during La Niña years, when tropical cyclone activity in the PACN region is reduced.

Flooding by storm waves wreaks havoc as a result of:

- the force of the moving water
- salt stress to plants and soils
- saltwater intrusion into the freshwater lens.

Listed below are effects of flooding by excessive rain:

- Changes to soil structure and chemistry
- Changes to nearshore sea water salinity
- Erosion/sedimentation harming both terrestrial and marine ecosystems. At WAPA and NPSA and in parts of Hawaii sedimentation is seriously degrading coral reefs.
- Habitat destruction leading to changes in species composition
- Biogeochemical cycling – excessive rain may leach soils, but if accompanied by strong winds, defoliation can also lead to extreme pulses of nutrients with consequences for terrestrial and marine systems.
- Destruction of roads and trails is a concern for visitor safety.

Flash floods are a particular concern at HALE with respect to visitor safety. Visitors often assume that swimming in pools or streams or hiking at the edge of streams is safe if the water level is low and there is no or little rain. However, as mentioned earlier microclimates in Hawaii vary dramatically over short distances and rainfall gradients are extremely steep at Haleakala. While it may be drizzling at lower elevations rainfall near the summit can be very heavy and flash floods several feet high can race down the stream beds without warning.

Droughts

Pacific Islands, particularly the low-lying islands, are very vulnerable to drought conditions as the only freshwater resources are the freshwater lenses and rainwater collection in tanks or reservoirs. The size of the freshwater lenses is directly proportional to the size of the island, thus small islands are less buffered from drought conditions during which the lens is not recharged (Carter et al. 2001, Meehl 1996). Under drought conditions ground water use increases leading to even more rapid depletion of aquifers and salt water intrusion.

In response to intensive ENSO related drought conditions a number of Pacific Island governments have formed drought task forces that serve to educate the public about expected drought conditions and measures to mitigate the consequences. In the summer of 2003 the Hawaiian Governor Linda Lingle, seeking federal assistance, issued a proclamation declaring that serious drought conditions existed throughout the state. The proclamation was made after the entire state experienced serious drought conditions for a year following several years that were drier than average.

Ecological Impacts of drought are listed below:

- Hydrologic effects, i.e. depleted soil moisture, surface and ground water
- Salt water intrusion into the fresh water lens
- Increased fire potential. 1998 El Niño conditions lead to a dramatic increase in fires on Pacific Islands (Shea et al. 2001).
- Soil structure and chemistry changes
- Vegetation effects including direct effects, i.e. vegetation dying due to water stress and indirect effects, such as changes in species composition with drought resistant, often alien, plants taking over.
- Effects on fauna due to lack of freshwater or host/feed plants dying
- Changes to the biogeochemical cycle

Precipitation and Temperature

Temperature and precipitation can vary widely as a result of natural climate variability. Determining the ranges of these parameters is an important part of characterizing an ecosystem. In addition to documenting temporal changes to precipitation and temperature it is also important to determine spatial variability. Particularly on the higher islands, extremely steep gradients exist for both of these parameters. Maintenance of a number of precipitation and temperature gauges in the larger parks and parks with several units is necessary to be able to link weather patterns and ecological effects. In addition to natural variability, changes in the patterns and trends of these parameters are expected as a result of anthropogenic climate change.

The IPCC (2001) reports that "mean rainfall intensity is projected to increase by approximately 20–30% over the tropical oceans at the time of doubling of CO_2". The pattern of increase is not uniform across the Pacific since it is dependent on the pattern of sea surface temperature. However, all the islands in the PACN are predicted to experience an increase of several mm/day as shown in map projections of the Hadley model and the Canadian model presented in the Pacific Assessment (Shea et al. 2001). Across the Pacific surface temperatures have increased in excess of global rates of warming over the last 90 years, between 0.3 to 0.8 ºC across much of the South Pacific (Shea et al. 2001) and over 2 ºC in Honolulu (EPA 1998).

Changes to precipitation and temperature patterns will affect:

- Hydrologic cycle (soil moisture, surface and ground water)
- Biogeochemical cycling
- Vegetation growth and physiology
- Development and growth rates of fauna
- Behavior of fauna. Feeding and reproductive behavior, for instance, is often linked to temperature clues.
- Habitat arrangements
- Increase in incident and geographic extent of vector borne diseases. For instance, the spread of mosquito populations is feared to increase the spread of avian malaria in Hawaii endangering endemic birds at HALE and HAVO and outside the parks (Benning et al. 2002). It is also feared that incidences in vector borne diseases affecting humans, such as Dengue Fever will increase.

Clouds

Clouds are an important climate component, but often receive little consideration in weather monitoring. Patterns of cloud presence, absence, thickness, height of base and ceiling affect rainfall, humidity, as well as in and outgoing radiation, (i.e., temperature and light experienced by plants and animals). In situations where clouds are low enough to interact with vegetation cloud water (fog) itself can be an important contributor to the hydrologic and nutrient cycles and information about cloud immersion time, liquid water content and cloud water chemistry are also of interest. Changes in cloud patterns may be caused by global climate change or can be due to land use change at upwind lower elevations (Lawton et al 2001). Some research also suggests that changes in species composition (introduction of alien plant species) may have an impact on the amount of cloud water that is intercepted. Changes in cloud characteristics will particularly affect sensitive cloud forest habitat which has evolved as a consequence of and is dependent on frequent and prolonged immersion in clouds (Stadtmueller 1987). In the PACN cloud forests are found at HAVO, HALE, KALA and NPSA. Research conducted in Hawaii by USGS BRD and the University of Hawaii, is focused on the narrow cloud belt that is created by the interaction of the trade winds and island topography. The concern is that this special ecological area which supports high endemism is particularly vulnerable to effects of global climate change (Loope and Giambelluca 1998). Even small changes to the lifting condensation level, which determines the height of the cloud base, and the trade wind inversion, which determines the cloud ceiling, can dramatically change the environmental conditions for this special ecosystem.

Wind

Relationships between the wind patterns and air quality and climate are also discussed in more detail under the heading Air Quality in the Drivers and Stressors section of this report. In summary, the dominant wind patterns in the PACN are the trade winds. Wind speed and direction affect air quality conditions everywhere. This is particularly noticeable on the island of Hawaii due to the presence of an active volcano, which represents a point source. Under normal trade wind conditions air quality is good at HAVO but fairly poor on the Kona side of the island. When the trade winds die down Kona air quality improves while conditions can seriously deteriorate close to the active vent, (i.e., at HAVO). On a larger scale, during changed wind regimes such as experienced during ENSO conditions air quality conditions on Guam and Saipan have been noticed to deteriorate due to haze from wildfires in Indonesia.

Information about wind speed is essential for estimates of evapotranspiration and dry deposition of gases and aerosols, (i.e. vegetation-atmosphere coupling). Furthermore, changes to wind speed and direction and the trade wind inversion affect cloud immersion time, crucial for cloud forest habitat at NPSA, KALA, HAVO, and HALE.

Sea Surface Temperature

Sea surface temperature (SST) across the Pacific shows significant spatial and temporal variation particularly associated with ENSO and PDO events. Nevertheless, a warming trend over the last 90 years has been confirmed in several studies for the South Pacific (Folland et al. 2003) as well as for the North Pacific. Models project a gradual increase in SST for the Pacific as a result of human activities (Carter et al. 2001).

Sea surface temperature (SST) is an important regulator of fish behavior. El Niño related increases in SST have been linked to changes in the distribution pattern of skipjack tuna in the Pacific (Lehodey et al. 1997). These shifts in distribution have brought some economic advantages to island communities that rely on commercial fisheries (Shea et al. 2001). However, little is known about the ecological effects of these changes to population distributions of skipjack and other fish species. An increase in SST has particularly detrimental effects on corals, as they can only tolerate narrow temperature brackets.

Extended periods of elevated SST have significantly contributed to coral bleaching of reefs of Samoa in 1994 and 2002 and in the CNMI in 1994, 1995, and 1997, and occasionally have also affected Hawaiian reefs (Wilkinson, 2002). These bleaching episodes can be detrimental to not just the corals, but the wealth of marine life that coral reefs support. Some studies suggest that disease outbreak is also enforced by elevated SST and is in part responsible for coral mortality (Harvell et al. 2001). Increased SST and associated changes to water quality such as a decrease in oxygen levels have been linked to more intense and frequent disease outbreaks in coastal areas (IPCC 2001).

Sea Level

The International Union of Geological Sciences compiled a list of geoindicators, which included relative sea level. Geoindicators are measures of physical processes that provide a science-based method to assess rapid change in the natural environment. The NPS Geologic Resources Division introduced geoindicators to NPS resource management in 2000 as a new ecosystem management tool (Higgins and Wood 2001).

Changes in sea level occur as both periodic changes associated with ENSO events and long term rise in sea level as a result of anthropogenic climate change. According to IPCC reports (Tsyban et. al 1990; Burkett et al. 2001) an average 1-2 mm/yr rise of SL has been recorded globally over the last century. In the Pacific there is no consistent trend for sea level, in some areas sea level has increased, which is attributed to global climate change, while in others it has decreased as a result of geologic uplift (Shea et al. 2001, NOAA CO-OPS 2004). Data for islands in the PACN are shown below. Trend data were not available for Saipan.

Table 2. Mean Sea Level Trends at Selected Pacific Island Stations

Location	Rate of change cm/decade	Record duration	Total change cm
Hawaii			
Honolulu	1.5 ± 0.2	1950-2000	14.2 ± 1.9
Kahului	2.1 ± 0.5	1950-2000	10.8 ± 2.6
Hilo	3.2 ± 0.5	1927-2000	23.9 ± 3.7
Guam	0.4 ± 0.6	1948-2000	2.0 ± 3.2
American Samoa	1.6 ± 0.5	1948-2000	8.5 ± 2.7

The above table is modified from the Pacific Assessment (Shea et al. 2001) which was based on data from the University of Hawaii Sea Level Center.

In the PACN the largest in sea lever occurred in the Hawaiian Islands. Within Hawaii the change in mean sea level rise varies; the highest rate of change has been experienced on the island of Hawaii. This is a result of subsidence of the island due to active volcanism. The IPCC lists seven key impacts of sea level rise on coastal systems:

- Lowland inundation and wetland displacement
- Shoreline erosion
- More severe storm-surge flooding
- Saltwater intrusion into estuaries and freshwater aquifers
- Altered tidal range in rivers and bays
- Changes in sedimentation patterns
- Decreased light penetration to benthic organisms

If the trends identified in the table continue, park ecosystems in the PACN could be severely affected. All PACN parks will be affected by increased storm damage due to higher reach of breaking waves which together with salt stress will lead to the destruction of coastal habitat which harbors native species. Particularly affected will be wetlands/mangrove shoreline at AMME, the coastal spray zone at KALA which harbors many endemic species and provides breeding habitat for endangered monk seals, as well as wetlands and anchialine ponds at PUHO, PUHE, KAHO and KALA. Potentially the growth of coral will be inhibited due to decreased light availability in increased water depth (Kennedy et al. 2002). This will add to other stress factors experienced by corals, such excessive erosion at WAPA and stress from increases in SST and storm damage for coral reefs in the entire PACN area.

Solar Radiation

Photosynthetically active radiation (PAR) is the light used by terrestrial and aquatic plants for photosynthesis. It includes wavelengths between 400 and 700 nm, which is the visible part of the electromagnetic spectrum. The availability and intensity of PAR is one of the key factors controlling net primary productivity. Estimates of PAR are thus an important aspect in understanding ecosystem processes. Information on PAR is derived from direct measurements of the 400 to 700 nm spectrum interval, by applying conversion factors to measurements of total solar irradiation, or by using satellite data (Pinker and Laszlo 1992). Possible consequences of climate change are that any changes in cloudiness would directly affect the amount of PAR reaching the earth (IPCC, 2001). Further concerns are that with increasing pollution the amount of PAR reaching plants could decrease due to scattering and absorption by aerosols (Bergin et al. 2001).

Ultraviolet (UV) radiation includes the wavelengths between 100 and 400 nm and is divided into 3 categories; UVA 320-400 nm, UVB 280-320 nm, UVC 100-280 nm. Little UVC reaches the biosphere. UVA is most prevalent in reaching the biosphere and is little affected by ozone. The amount of UVB reaching the earth is largely controlled by the amount of ozone in the stratosphere. Depletion of stratospheric ozone due to pollution has globally led to an increase in UVB received by the biosphere. Ultraviolet wavelengths can damage DNA and concerns focus on the detrimental effects of UVB to human health, terrestrial animals, phytoplankton and zooplankton, and suppression of photosynthesis in plants (Diffey 1991). Within the PACN the contribution of increased UV to coral bleaching is of particular concern. Not all effects of UV radiation are negative. It has been found that UV radiation also plays an important role in providing environmental information to plants, fungi and animals. Photoreception of UV has been found to influence development of plants and fungi and use of UVA vision determines the behavior of vertebrates as well as invertebrates (Paul and Gwynn-Jones 2003). The effects of changed levels of UV on processes dependent on photoreception still need to be assessed.

Deposition & Nutrient Cycles

Nutrient cycles are driving forces for ecosystem processes, determining for instance, succession, primary productivity, species composition, susceptibility to disease, and success of invasive species. Atmospheric deposition loads, litter decomposition, weathering and many other aspects of biogeochemical cycling are strongly dependent on temperature and precipitation regimes (Vitousek 2004). Therefore, changes in these climate parameters will affect the cycling of nutrients through ecosystems.

Atmospheric Deposition Pathways

Monitoring of atmospheric deposition in all PACN parks is important to understanding ecosystem processes and possible changes to these processes as a response to climate change or variability and/or pollution. Overall atmospheric deposition is the total of wet deposition (i.e. precipitation only), dry deposition of particulates and gases and cloud water deposition. The relative importance of any one of these parameters varies for parks in the PACN and even for areas within parks.

For most ecosystems in the PACN parks wet and dry deposition are the major atmospheric deposition pathways. The importance of each pathway varies with location such as elevation, windward versus leeward and proximity to a (volcanic) point source. For cloud forest habitat, found at HAVO, HALE, KALA and NPSA cloud water deposition (fog interception) may provide the majority of nutrients (Stadtmueller 1987). At HAVO the Huebert (UH Manoa) research group has found that montane cloud forest receives over 90% of N via cloud water (Heath and Huebert 1999). An unusual pathway was found for high N concentrations in cloud water. Ambient N_2 is fixed at hot lava surfaces converted to HNO_3 and carried upslope by winds where it dissolves in orographic fog.

Nitrogen & Phosphorus

N and P are the two main nutrients driving ecosystem processes. Besides deposition, weathering, decomposition, mineralization and demineralization are the main processes involved in making these and other nutrients available for ecosystems. The Hawaii Ecosystems Project led by Peter Vitousek of Stanford University has done extensive research at HAVO as well as several other sites across the Hawaiian Islands to elucidate these pathways (Vitousek 2004). Results show that young Hawaiian ecosystems are N limited, (i.e. atmospheric N input is important), while older Hawaiian ecosystems are P limited. These and other results of this group help us in understanding not just Hawaiian but also other volcanic island ecosystem processes. All islands in the PACN are of volcanic origin. However, despite their similarities in origin and geographic setting differences exist due to local weather regimes, differences in substrate age, topography, and species composition, necessitating on-site studies.

Carbon

Atmospheric CO_2 concentrations have increased globally making resulting climate change and CO_2 sequestration important issues for all PACN parks. Increased CO_2 levels affect ocean chemistry and thus marine ecosystems, as well as terrestrial ecosystems.

Many plants are limited by CO_2. Mueller-Dombois (1992), conducting research on native Hawaiian trees states that increased CO_2 will lead to increased primary production and leafier canopies. However, it may also mean shorter life-spans and hastened senescence which may be an additional stress factor in forest decline. Increased CO_2 levels have also been correlated with an increase in belowground biomass and resulting changes to microbial and microarthropod populations (Rillig et al. 1999, Schortemeyer et al. 1996). There is also evidence that increased carbon sequestration affects the cycling of other nutrients, for instance it has been linked to increased nitrogen mineralization (Ebersberger et al. 2003).

Increased ocean sequestration of CO_2 lowers the pH, affecting surface ocean carbonate chemistry and, in turn, planktonic organisms with carbonate skeletons (Kennedy et al. 2002). Many of these organisms are involved in air-sea exchange processes. Diminishing populations of these organisms may affect these processes as well. Changes in carbonate chemistry would also affect the growth of coral reefs exacerbating existing stresses for coral reefs due to other climate change factors and pollution.

CRITICAL RESOURCES & MONITORING NEEDS

All the parks have a diverse array of natural resources with the exception of USAR. Table 3 lists critical natural resources and potential threats to them. Note that parks may have many more resources. Only resources that may be affected either directly or indirectly by changes in air-quality or climate conditions were selected for this table. The natural resources are listed as habitats rather than individual genera or species, with the implication that these habitats are harboring many native or endemic species whose survival would be threatened by habitat destruction or fragmentation, or direct impacts of stressors.

Table 3. Critical Resources and Stressors related to Air Quality and Climate

Park	Resources	Potential Stressors
AMME	Stream Wetland/Mangrove shoreline Coastal communities	∆ in T & P patterns, UV ↑ ∆ in P patterns, SL ↑ SL ↑ storm frequency & intensity ↑
WAPA	Wetlands Streams Forest Coral reefs Coastal communities	∆ in T & P patterns, UV ↑, SL ↑ ∆ in T & P patterns, UV ↑ ∆ in T & P patterns, UV ↑ SST ↑, UV ↑, CO_2 ↑, SL ↑, storm frequency & intensity ↑ SL ↑, storm frequency & intensity ↑
NPSA	Cloud and Rain forest Streams Coral reefs Viewscapes Coastal communities	∆ in T & P & cloud patterns, UV ↑ ∆ in T & P patterns, UV ↑ SST ↑, UV ↑, CO_2 ↑, SL ↑, storm frequency & intensity ↑ Haze/smoke SL ↑, storm frequency & intensity ↑
USAR	Coral reef Coastal communities	SST ↑, UV ↑, CO_2 ↑, SL ↑, storm frequency & intensity ↑ SL ↑, storm frequency & intensity ↑
KALA	Cloud and Rain forest Lowland dry forest Crater Lake Streams Anchialine pools Coral reefs Coastal communities	∆ in T & P & cloud patterns, UV ↑ ∆ in T & P patterns, UV ↑ ∆ in T & P patterns, UV ↑ ∆ in T & P patterns, UV ↑ ∆ in T & P patterns, UV ↑, SL↑ SST ↑, UV ↑, CO_2 ↑, SL ↑, storm frequency & intensity ↑ SL ↑, storm frequency & intensity ↑
HALE	Cloud and Rain forest Montane mesic forest Bogs and lakes Streams Viewscapes Coastal communities	∆ in T & P & cloud patterns, UV ↑ ∆ in T & P patterns, UV ↑ ∆ in T & P patterns, UV ↑ ∆ in T & P patterns, UV ↑ Haze/smoke SL ↑, storm frequency & intensity ↑
ALKA	Anchialine pools Streams Coastal communities	∆ in T & P patterns, UV ↑, SL↑ ∆ in T & P patterns, UV ↑ SL ↑, storm frequency & intensity ↑
PUHE	Stream Anchialine pools Coral reefs Coastal communities	∆ in T & P patterns, UV ↑ ∆ in T & P patterns, UV ↑, SL ↑ SST ↑, UV ↑, CO_2 ↑, SL ↑, storm frequency & intensity ↑ SL ↑, storm frequency & intensity ↑

Park	Resources	Potential Stressors
KAHO	Anchialine pools Wetlands Coral Reefs Coastal communities	Δ in T & P patterns, UV ↑, SL ↑ Δ in T & P patterns SST ↑, UV ↑, CO_2 ↑, SL ↑, storm frequency & intensity ↑ SL ↑, storm frequency & intensity ↑
PUHO	Anchialine pools Wetlands Stream Coastal communities	Δ in T & P patterns, UV ↑, SL ↑ Δ in T & P patterns, UV ↑, SL ↑ Δ in T & P, UV ↑ SL ↑, storm frequency & intensity ↑
HAVO	Cloud and Rain forest Montane mesic forest Streams Viewscapes Anchialine pools Coastal communities	Δ in T & P & cloud patterns, UV ↑ Δ in T & P patterns, UV ↑ Δ in T & P patterns, UV ↑ Haze/smoke, vog Δ in T & P patterns, UV ↑, SL ↑, vog SL ↑, storm frequency & intensity ↑

In this table T = temperature, P = precipitation, SST = sea surface temperature, SL = sea level, ↑ denotes an increase and Δ denotes a change.

Habitats listed in Table 3 are characterized by either having high biodiversity or high endemism, (e.g. coral reefs, bogs or cloud forest), and/or are supporting rare and endangered species, (e.g. cloud forest or coastal zones). Table 3 shows that in all the parks in the PACN these critical natural resources are potentially threatened by climate change and variability and changes to air quality conditions. For many of these resources baseline conditions have not been inventoried, complicating evaluation of the effects of possible changes. Climate variability, in particular extreme conditions during ENSO events, and their impacts on natural resources in the PACN region are the focus of research projects by the USGS, the WWF, NPS I&M program inventories and others. It is presumed that El Niño conditions may provide an analogue for conditions in a future greenhouse climate. The USGS is investigating the increase in the range of mosquito populations due to changing temperature and precipitation patterns. The associated spread of avian malaria and avian pox is endangering endemic birds at HALE and HAVO, and in areas outside of the parks on several Hawaiian islands. The USGS Global Change Program in Hawaii is also investigating the effect of El Niño related changes to the TWI on cloud and rain forest habitat at HALE and HAVO and plans to initiate work at NPSA. The WWF is investigating the effect of climate variability, especially changes to SST and UV radiation, on coral reefs at NPSA and other parts of American Samoa.

MINIMUM METEOROLOGICAL PARAMETERS

For some climate parameters, particularly for temperature and rainfall, steep gradients exist on several PACN islands. For this reason, measurements from stations located outside the parks are not always useful in evaluating impacts of climate variability. NPS guidelines for natural resources inventory and monitoring (NPS, no date) recommend a minimal set of parameters to provide information about climate and air quality which should be available in all parks. Existing monitoring efforts for these parameters in PACN parks are summarized in Table 4.

Table 4. Existing (2004) Monitoring of Recommended Minimum Meteorological Parameters within NPS Boundaries

Parks	Parameters	Precip. amount	RH	Wind speed and dir	Temp. max & min	List of AQRVs	List of visibility goals	Location of nearby AQ stations/sources
NPSA								
Tutuila unit								X
Tau unit								
Ofu unit								
Olosega unit								
WAPA								
Piti Guns unit								
Mt. Tenjo/Mt. Chachao unit								
Mt. Alifan unit								
Agat unit								
Asan beach unit								
Asan inland unit		*	*	*	*			
Fonte plateau unit								
AMME								
USAR								X
KALA		X	X	X	X			
HALE		X	X	X	X	X	X	X
HAVO		X	X	X	X	X	X	X
ALKA								
PUHE		X			X			
KAHO		X	*	*	*			
PUHO		X						X

** = monitoring will start in the near future; X = current monitoring*

As demonstrated in Table 4, data collection for even the minimum recommended meteorological parameters is often inadequate in the PACN parks. However, for small park units and particularly for parks with minimal changes in elevation data from nearby stations will be adequate. In many cases obtaining data only requires locating existing nearby stations and ensuring that data are downloaded regularly. Data from RAWS (Remote Automated Weather Stations), CASTNet (Clean Air Status and Trends Network) stations and NPS gaseous pollutant network stations are available for free online. The NOAA CMDL observatories in Hawaii and American Samoa also make their meteorological data available online. Data from NWS COOP (National Weather Service Cooperative Observer Program) stations and NWS ASOS (Automated Surface Observing System) can be obtained from the National Climatic Data Center (NCDC) for a minimal fee. The I & M program is compiling a database for the PACN that will show station locations, provide metadata for the stations, links to webpages for data access and, for some stations, historical data sets. Details about the monitoring efforts and needs are provided in the following list:

- NPSA is not conducting meteorological measurements at any of the four park units. The summary report (Craig 2001) from a vital signs workshop includes recommendations for regular monitoring of temperature, rainfall and other meteorological data. For Tutuila several decades of data are available for the NOAA CMDL observatory site. Current data for NWS stations on Tutuila and Tau can be obtained from the NWS website. The NWS station on Ofu was damaged in a Hurricane in 2002 and has not yet been replaced. Given the steep elevation of Tau and the fact that the NWS station is located at the opposite side of the island at sea level, it may be desirable to install a weather station at the Tau unit.
- WAPA is not measuring any meteorological parameters. Park personnel are installing a RAWS station in the Asan unit and data collection is to start in the near future. Additionally, the USGS WRD operates 8 rain gauges on Guam; one of them in close proximity to the Piti Guns unit. The need for basic meteorological measurements and radiation, especially PAR, for at least some of the park's units has been stressed by the natural resource manager. Some relevant weather data can be obtained from the USGS stations. In addition, there are several NWS COOP stations on the island.
- AMME is not collecting meteorological data. Given the small size of the island and minimal elevation changes, data from stations outside the park would provide adequate information. Weather stations on the island are maintained by the NWS, USGS and the University of Guam Water and Energy Research Institute (WERI).
- USAR is not collecting meteorological data. The Fleet Weather Service collects data nearby. Though, only current data are available online for the Fleet station. Data for nearby NWS COOP stations can be obtained from the NCDC website.
- KALA covers an area from sea level to the top of a steep cliff (914m), the rainfall and temperature gradients are steep because the peninsula is located on the windward side of the island and the cliff is a barrier to clouds. The Resources Management Plan states the need to establish baseline conditions for climate parameters. A single RAWS station provides meteorological data for the park. Data collection for two additional RAWS stations at different elevations is planned. Additional RAWS stations are located in the adjacent Natural Area Reserve. A NWS station is also located nearby. Acquiring adequate weather data could be accomplished by setting up a database and regularly downloading the data for these stations.
- HALE is also well covered by meteorological monitoring stations as part of RAWS and Hale Net, the Haleakala Climate Network. Additional parameters besides the ones listed in Table 4 are monitored (see Table 5). More data can be obtained from several NOAA COOP stations on Haleakala and other parts of Maui.
- HAVO has a number of monitoring stations in locations spread out across the park, with the exception of the newly acquired Kahuku ranch area. Some of the stations monitor additional parameters besides the ones listed in Table 4 (see Table 5). Weather monitoring includes data collection as part of ongoing research projects (USGS-BRD, USGS-HVO), mandatory air quality monitoring and RAWS stations for fire weather monitoring.

- ALKA NHT was only designated in 2000 and staffed in 2002. The trail corridor runs through all NPS units on Hawaii Island. No weather monitoring is conducted aside from observations made at the national parks which it connects. Park staff indicates the need for weather observations along the trail. The data will serve to inform visitors of extreme weather conditions that may pose a health and safety risk, it will be used to predict likelihood of brush fires and to determine weather related impacts on shoreline flora and fauna and ocean resources. Several NOAA COOP ASOS stations are located in the vicinity of the trail. The trail also connects several national parks that measure rainfall and/or temperature. It appears that obtaining adequate weather data for ALKA could be accomplished by taking advantage of the existing nearby COOP and other NWS stations.
- PUHE collects rainfall and temperature data. Given the small size of the park one station seems adequate. Additional data for upslope COOP stations can be obtained from the NCDC website.
- KAHO is operating a single rain gauge. The need for weather data at KAHO is stated by several scientists who are conducting research projects on marine as well as terrestrial species. The Inventory and Monitoring Program is installing a weather station in conjunction with a survey of the anchialine pools. Additional weather data can be obtained from the NWS ASOS station at the nearby airport and NOAA COOP stations.
- PUHO maintains a rain gauge only. Additional information can be obtained by downloading data for nearby COOP stations.

ADDITIONAL METEOROLOGICAL AND AIR QUALITY PARAMETERS

NPS guidelines (NPS, no date) list additional parameters for which data collection is desirable to characterize ecosystems and determine their status. Monitoring efforts for these additional parameters are listed in Table 5.

Table 5. Monitoring of Additional Air Quality & Climate Parameters

Parameters	NPSA	WAPA	AMME	USAR	KALA	HALE	HAVO	ALKA	PUHE	KAHO	PUHO
Meteorology											
Rainfall	n	n	n	n	X	X	X	n	X	X	X
Temperature (2m agl)	n	n	n	n	X	X	X	n	X	n	
Temp diff (10m—2m)	n						X				
RH (or dew pt)	n	n	n	n	X	X	X	n	n	n	n
Wind Speed	n	n	n	n	X	X	X	n	n	n	n
Wind Dir. (incl. std dev)	n	n	n	n	X	X	X	n	n	n	n
Total Solar Radiation	n				X	X	X				
UV Radiation	n						X				
Cloud immersion time											
Surface wetness							X				
Fuel Moisture					X		X				
Soil Moisture					X	X	X				
Mixing Height	n					X					
Atmospheric Gases											
SO_2	n						X				
O_3	n						p, Xn				

Parameters	NPSA	WAPA	AMME	USAR	KALA	HALE	HAVO	ALKA	PUHE	KAHO	PUHO
NO/NO2	n						X				
HNO_3	n						X				
Non methane organics	n						X				
CO_2	n						X				
N2O	n						X				
CH4	n						X				
CFCs	n						n				
Total Organic Chlorine											
Atmospheric Particulates											
SO4	n						X				X
NO_3-	n						X				
H+	n						X				
NH4+	n						X				
Ca++	n						X				
Mg++	n						X				
Pesticides											
Trace Metals (Na-Pb)	n						X				
EC/OC											
Aerosol Acidity											
Wet Deposition											
Precipitation											
Alkalinity/Acidity							X				
PH	p-n						X				
Conductivity	p-n						X				
SO4	p-n						X				
NO_3-	p-n						X				
PO4	p-n						X				
Cl-	p-n						X				
NH4+	p-n						X				
Ca++	p-n						X				
K+	p-n						X				
Na+	p-n						X				
Mg++	p-n						X				
Peroxides							X				
Pesticides											
Trace Metals							X				
Organic Anions							X				
Cloud/Fog											
SO4							p				
NO_3-							p				
H+							p				
NH4+							p				
Peroxides											
Visibility											
Atmospheric extinction	n					X	X				X
Atmospheric scattering	n					X	X				
View						p	p				
Additional parameters (not in NPS 75)											
Relative Sea Level											
Tides/Swells											

Parameters	NPSA	WAPA	AMME	USAR	KALA	HALE	HAVO	ALKA	PUHE	KAHO	PUHO
Sea Surface Temperature	X	n								X	

In this table X = current monitoring, p = past monitoring, n = nearby (not inside park), f = future monitoring (to start soon)

Details about the monitoring efforts and needs are listed below:

- NPSA: No meteorological and no air quality measurements are made in the national park. However, NPSA benefits from the fact that the NOAA CMDL observatory on Tutuila is located only about 15 km to the east of the park. Extensive measurements of aerosols, gases, solar radiation, and meteorological parameters have been conducted at this site for almost 30 years. An NADP station was located at the observatory site in the past providing data on precipitation chemistry.
- WAPA: No data for air quality are collected in the park. NOAA CCGG is collecting data for greenhouse gases.
- AMME: There are no data on atmospheric nutrient and/or pollutant input.
- USAR: No monitoring is taking place in the park. The DOH has been monitoring PM10 in Pearl City for over 30 years.
- HAVO and HALE: Under the stringent requirements for Class I areas aerosol concentrations and dry deposition are measured in both of these parks. At HAVO wet deposition is also measured. However, given the presence of a point source (i.e., Kilauea volcano) and the observed spatial variation of the vog plume it is likely that the measurements of precipitation chemistry from only one site are not representative for the whole park.
- PUHO: For a six months period in 2003 particulate matter was measured at the park as part of VOGNET, providing some information on input from volcanic emissions. Results of the study are not yet available. No other studies have been conducted to estimate atmospheric nutrient input or pollution.
- KAHO: There are no data on atmospheric nutrient and/or pollutant input. KAHO staff is concerned about the possible human health and ecosystem effects of frequent dust plumes from two nearby quarries.
- KALA, ALKA, PUHE: There are no data on atmospheric nutrient and/or pollutant input.

The blank cells in Table 5 demonstrate the need for information about air quality and climate parameters in most of the parks. Selection of air quality and climate vital signs for each park and for the network as a whole will take careful consideration of the needs for protection of the critical resources as listed in Table 3, the level of threat from stressors, as well as the need for baseline data to characterize these ecosystems.

Determining Assessing spatial and temporal patterns is invariably a compromise between research needs and available funds for equipment, analysis, and manpower. Critical assessment of individual air quality and climate parameters, and the monitoring objectives is necessary to determine the geographic and time scales for measurements. Priorities for monitoring of spatial and temporal patterns will differ between parks for any given parameter. Assessment of these details for any given vital sign or parameter will be part of the third phase of the monitoring report in which monitoring protocols will be developed.

MONITORING

The Clean Air Act places some of the responsibility for maintaining good air quality in protected areas on the stewards of those lands (i.e. the National Park Service). Monitoring efforts depend on the classification of the area according to the CAA. The parks in the PACN are classified as either Class I or Class II areas, with the following definitions:

- Class I area: includes national parks greater than 6,000 acres, wilderness areas and national memorial parks greater than 5,000 acres, and international parks that existed as of August 1977.
- Class II areas: Areas of the country protected under the Clean Air Act, but identified for somewhat less stringent protection from air pollution damage than Class I, except in specified cases.

Table 6. Classification of PACN parks according to the CAA

Class	WAPA	AMME	NPSA	USAR	KALA	HALE	ALKA	PUHE	KAHO	PUHO	HAVO
I						x					x
II	x	x	x	x	x		x	x	x	x	

In Class I areas, monitoring for visibility is mandated under the Regional Haze Rule. Other air quality monitoring is not mandatory, but is considered necessary in order to carry out our Congressional mandate to protect air quality related values in Class I areas.

The following sections list past and ongoing monitoring efforts for various parameters. The I & M Program is compiling a database that will provide more details about sites, data collection periods, instruments used, and data access. In the following sections monitoring programs, agencies, institutions and parameters measured are generally identified by their acronyms. Appendix A lists acronyms used in this report.

VISIBILITY

Visibility is monitored through IMPROVE in the two Class I parks, HAVO and HALE. The program is designed to establish current visibility and aerosol conditions in mandatory Class I areas; identify chemical species and emission sources responsible for existing man-made visibility impairment; document long-term trends for assessing progress towards the national visibility goal; and provide regional haze monitoring representing all visibility-protected federal Class I areas where practical. Visibility and air quality conditions have been assessed using camera view data and reconstructed light extinction values based on dry aerosol measurements.

Camera view data are available for the period from 1986-1995 for HAVO and for 1987-1995 for HALE. Aerosol monitoring has been ongoing for 10 to 15 years at HAVO, HALE and also at an additional site on the island of Hawaii at Mauna Loa Observatory.

PARTICULATE MATTER & DRY DEPOSITION

Particulate matter (PM) is monitored by various agencies in many locations in the state of Hawaii, especially on the island of Hawaii. On Saipan and Guam no PM monitoring is currently taking place either within or outside the national parks. In American Samoa no monitoring is taking place inside NPSA but NOAA monitors close by. The following networks and agencies are monitoring particulate matter in the PACN region:

- IMPROVE has sites on the island of Hawaii at Mauna Loa Observatory and HAVO as well as a site near HALE on Maui.
- CASTNet collected data at HAVO as part of PRIMENet from 1999-2004.
- NOAA CMDL labs at Mauna Loa, Hawaii (1960's to present) and Cape Matatula, American Samoa (1970's – present) are involved in similar work outside PACN parks, with their own protocols.
- VOGNET is a collaboration of NOAA-CMDL and 6 high schools. Eight stations on the island of Hawaii collect data during the school year.
- DOH is collecting data at 10 SLAMS/NAMS sites in the Hawaiian Islands; some of these sites are close to national parks. The sites were established at various times between 1971 and 1991.
- Huebert research group (UH Manoa) has measured aerosols at Mauna Loa Observatory since 1990 and at HAVO from 1994-2003. They have a longer record than CASTNet for sulfate aerosols at the same HAVO site.

GASEOUS POLLUTANTS & DRY DEPOSITION

Gaseous pollutant monitoring /dry deposition is a widespread and significant concern, especially on the island of Hawaii, in conjunction with active and long-term ongoing volcanic emissions. The NPS Air Resources Division, Gaseous Pollutant Monitoring Network sponsors three sites in HAVO, collecting ambient & real-time concentration data. These sites collect some similar, and some unique data parameters, identified below. Various other groups collect data on SO_2/aerosol pollution using active or passives samplers throughout the island of Hawaii, especially in the windward vicinity of Puu Oo vent and downwind (leeward) areas of the island especially prone to vog. Volcanic emissions are of interest to USGS-HVO as well as other parks with active volcanoes.

On Saipan no gaseous pollutant monitoring is currently taking place either within or outside the national park. In American Samoa no monitoring is taking place inside NPSA but NOAA CMDL monitors within 10 miles of the Tutuila unit. The following gaseous pollutants are monitored in the PACN region:

- O_3 is monitored continuously, real-time at HAVO and HALE as part of the NPS Gaseous Pollutant Network. In addition, total column O_3 was derived via the solar radiation measurements as part of UV NET/PRIMENet at the HAVO HVO site from 1999-2004. The Hawaii DOH measures O_3 continuously at one NAMS site on Oahu, Hawaii (1981- present). O_3 is also monitored by NOAA CCGG Stations (Mauna Loa 1958- present, American Samoa 1974 – present, Guam 1979 - present)
- CO_2 monitoring in PACN parks is primarily focused on volcanic emissions. Work by USGS-HVO at HAVO includes data collection on real-time concentrations

downwind of fumarolic vents, emission rates from Kilauea summit, and mapping ground level concentrations in the Kilauea summit caldera.

- CO_2 as well as CO and other greenhouse gases are monitored outside PACN parks at NOAA CCGG sites (Mauna Loa 1958 - present, American Samoa 1974 – present, Guam 1979 – present). These sites part of a long term effort to document global trends and patterns in mixing ratios of greenhouse gases. NOAA CMDL at MLO also monitors volcanic emissions of CO_2.
- SO_2 is monitored at HAVO continuously, real-time behind KVC and at HVO as part of the NPS gaseous pollutant network (2001- present). Huebert Research group (UH Manoa) conducted a pilot study to investigate spatial variation of SO_2 (and NO_2) at HAVO. HVO is measuring real-time concentrations downwind of fumarolic vents as well as emission rates from Kilauea summit caldera.
- H_2S is currently not monitored within HAVO, but an extensive study was conducted at nine sites on Kilauea between 1986 and 1990 at several sites around Kilauea by USGS HVO. Mixing ratios of H_2S were found to be low. The Hawaii DOH maintains two monitoring stations (1992/93 – present) in the Puna District close to HAVO and in close proximity to a geothermal power facility.
- Hg is currently not monitored by either HVO or the Hawaii DOH. However extensive studies of volcanic emissions of Hg and contamination of plants and soil were conducted by B. Siegel and S. Siegel (UH Manoa) in the late 1970s and 1980s.

WET DEPOSITION

Wet deposition here refers to precipitation deposition only. No wet deposition estimates are available for Saipan and Guam. The following networks and university researchers have estimated wet deposition:

- NADP/NTN has collected precipitation chemistry data at three sites in the PACN region. Data collection at HAVO started in 2000 and is ongoing. A second site on the island of Hawaii was located at the NOAA CMDL Mauna Loa Observatory from 1980 – 1993. In American Samoa at the NOAA CMDL observatory site on the island of Tutuila data were collected from 1980 – 1992.
- Huebert research group (UH Manoa) has collected bulk precipitation anion and cation data at HAVO from 1995 to 2003 using their own sampling and analytical protocols. Their collector, which was identical to the NADP collector, was co-located with the NADP collector.

CLOUD OR FOG WATER

Cloud water interception has been estimated as part of several hydrological studies in Hawaii. Nutrient deposition via cloud water was investigated only by one research group. No cloud water research has been conducted in Saipan, Guam and American Samoa. Cloud water data have been collected by the following researchers:

- The Huebert research group (UH Manoa) has monitored cloud presence and performed cloud water chemical analysis/deposition estimates intermittently from 1997 to 2003 at HAVO.

- USGS-WRD (M. Scholl) and University of Hawaii (T. Giambelluca) – are conducting isotope tracer studies to assess the contribution of fog to the water budget at 2 sites on the slopes of Haleakala close to HALE.
- Studies of fog water interception in various locations on the island of Hawaii have been conducted by the Juvik research group (UH Hilo).

SOLAR RADIATION

Solar radiation of various wavelengths has been measured in several locations in the PACN:

- UV radiation was monitored at a PRIMENet/UVNet station at HAVO from 2000 - 2004. Outside national parks UV is monitored at NOAA CMDL observatories at Mauna Loa, Hawaii and Cape Matatula, American Samoa. Intermittent UV monitoring has also been conducted by the WWF at NPSA in conjunction with coral reef studies.
- CMDL observatories also perform other solar and thermal atmospheric radiation measurements mainly for climate modeling and calculation of the earth's surface radiation budget.
- Total radiation data was collected as part of the PRIMENet/CASTNET measurements at HAVO (1999-2004).
- Visible light and PAR wavelength data are also often collected at automated weather stations, such as the RAWS stations which are used in several of the parks in the PACN.

METEOROLOGY

Numerous NOAA COOP stations exist on all the islands on which PACN parks are located. Additionally, the NWS operates weather stations at all the airports. USGS also operates weather stations on several islands. Though these stations often do not measure many parameters; primarily USGS WRD measures rainfall in conjunction with hydrological studies.

- AMME – no meteorological data are currently being collected at this park.
- WAPA – No meteorological data have been recorded in any of the park units so far. Data collection using a RAWS station is to start in the near future in the Agat unit. USGS WRD operates several rain gages on the island.
- NPSA- No meteorological data have been recorded in any of the park units so far. Outside the park meteorological data are being collected at the NOAA CMDL observatory.
- USAR – NPS is not collecting meteorological data, but the Fleet Weather Services has a weather station in Pearl Harbor.
- ALKA- no meteorological data are currently being collected at this park.
- HAVO – meteorological data are collected as part of the CASTNET and IMPROVE air quality measurements. In addition, 2 RAWS stations are installed. USGS-HVO also operates two met station.
- PUHE – temperature and rainfall are measured by a NWS station.
- PUHO – at this time only precipitation is being measured.
- KAHO – at this time only precipitation is being measured. An automated weather station will be installed in the near future.

- HALE – 12 Hale Net stations collect extensive meteorological data in addition to soil moisture and temperature. Additionally, one RAWS station is installed in the park.
- KALA – a single RAWS station provides meteorological data at this time. There are plans for two additional RAWS stations.

CLIMATE & CLIMATE MAPPING

The coarse scale of global climate maps does not allow description of regional climate patterns for Pacific Islands. Due to limited land mass, precipitation data and air temperature data are incomplete, providing a challenge for regional climate mapping. Progress in maps that include open ocean areas is being made by incorporating remote sensing data and inferring air temperature from sea-surface data collected by buoys.

Some regional climate maps with fairly good grid resolution exist for some islands in the PACN, not including open ocean areas between islands. Maps for the Hawaiian Islands for monthly precipitation, minimum, maximum, and mean temperature and mean dew point exist for the time period of 1961-1990. The Spatial Climate Analysis Service (SCAS) which is located at Oregon State University (OSU) prepared these maps at 30 arc second grid resolution. SCAS/OSU also prepared 15 arc grid resolution maps for mean monthly precipitation only for several other islands and island groups in the Pacific Basin.

Currently NPS is entering into an agreement with SCAS/OSU to produce a climate map for the Pacific Island Region. This will include 1971-2000 mean monthly minimum, maximum, and mean temperature, mean dew point, and precipitation maps at 15 arc seconds or better resolution. The maps will cover the Hawaiian Islands (from Niihau in the northwest to Hawaii in the southeast), Palau, Guam, CNMI (Saipan, Tinian, and Rota), Tutuila and the Manua Islands in American Samoa and in Federated States of Micronesia the islands of Kosrae and Pohnpei. All maps that will be produced under this new agreement and maps previously produced by SCAS/OSU for the Pacific region are based on the PRISM model. This model includes data from many meteorological stations and also takes into account several topographic features.

Climate maps that are based only on meteorological data (i.e., without taking terrain into account) are available from NOAA CPC. These include maps for open ocean areas as well as for islands. NOAA CPC maps are available for many atmospheric and oceanic parameters. Other climate information such as ENSO and tropical cyclone forecasts are available from NOAA CPC, the NWS and its regional forecast offices and the PEAC.

SEA SURFACE TEMPERATURE

No long term monitoring of sea surface temperature is conducted in any of the parks, but some monitoring has been done in conjunction with coral reef studies. For instance, by the WWF at NPSA and by the NPS Pacific Coral Reef Program at KAHO.

SEA LEVEL

No measurements of relative sea level are conducted in any of the individual PACN national parks. However, relative sea level in the PACN region is monitored by NOAA and the UHSLC.

PROTOCOLS

Various organizations collect air quality and climate data, many use existing methodologies and protocols whenever appropriate. Adoption of existing protocols for measurements in the PACN parks will ensure that the data collected are comparable with a wider set of data from other monitoring networks. In general, protocols include guidelines and standard operating procedures for site selection, equipment specifications, installation requirements, site maintenance, calibration procedures, sample handling, sample analysis, quality assurance and control, and training requirements for station operators. Table 6 lists widely accepted and established protocols that are currently used in various monitoring efforts within the PACN.

Table 7. Protocols for Air Quality and Climate Monitoring

Organization	Protocol/Guidelines for	URL or reference
CASTNET	Dry deposition monitoring meteorological observations	http://www.epa.gov/castnet/library/qapp.html
EPA & DOH Hawaii NAMS/SLAMS/PAMS	Air toxics and particulate monitoring	http://www.epa.gov/ttn/amtic/
IMPROVE (EPA)	Visibility/ particulate monitoring	http://vista.cira.colostate.edu/improve/Publications/SOPs/UCDavis_SOPs/IMPROVE_SOPs.htm
NADP/NTN	Wet deposition monitoring	http://nadp.sws.uiuc.edu/QA/
NOAA NWS COOP	Weather monitoring	http://www.nws.noaa.gov/om/coop/
NOAA NWS ASOS	Weather monitoring	http://www.nws.noaa.gov/asos/index.html
RAWS/NFDRS	Weather monitoring	http://www.fs.fed.us/raws/standards/NFDRS_rev0402.pdf
PRIMENet	Collection of radiometric data for calculation of in situ extinction coefficients	http://www.forestry.umt.edu/research/MFCES/programs/primenet/Assets/radiometer/SOP.pdf

CONCLUSION

The effect of air pollution on human health and the environment has been the focus of much research over the last several decades. Pollution is worst in and near urban centers. Though, often, protected lands even in remote locations are also impacted by air pollution. The desire to protect these lands lead to research and monitoring efforts in National Parks, in part mandated by federal laws. In the PACN extensive monitoring of gaseous and particulate air pollutants is taking place in HAVO and HALE as a result of federal mandates. In other PACN parks air quality is not monitored. However, NOAA and the Hawaii Department of Health are monitoring aerosols and gases on several islands on which PACN parks are located.

The main pollution source of air pollution in the PACN is volcanic activity. Kilauea Volcano emits tons of gases and particulates daily. The resulting pollution mainly affects HAVO but also other national parks on the island of Hawaii and occasionally HALE on Maui. On rare occasions volcanic eruptions of Anatahan have resulted in air pollution on Guam and Saipan. Other sources of air pollution in the PACN are long range transport of pollutant plumes from the Asian or North American continents. These plumes are particularly noticeable during El Nino years when wind regimes change for prolonged periods of time. Additionally, increased urbanization affects air quality through emissions from vehicles and industrial operations.

No strict federal or state legal mandates exist regarding the monitoring of climate. However, NPS Natural Resources Inventory and Monitoring Guideline (NPS no date) lists minimum and desired parameters that should be monitored to characterize ecosystems. Impacts of climate change and extreme weather events on terrestrial as well as marine resources have prompted extensive interest in climate and meteorology throughout the Pacific. Climate change or variability is already affecting ecosystems in the PACN. For instance, coral reefs are suffering from episodes of bleaching due to increased UV radiation and sea surface temperatures. The range of mosquitoes is expanding due to changes to precipitation and temperature patterns. It is feared that as a result vector borne diseases carried by mosquitoes, such as avian malaria, are also spreading. University faculty and researchers have many times been at the forefront of such monitoring and issue identification. However, academic research projects are often of limited duration and may not be located in protected areas. Monitoring of even basic weather parameters in the PACN parks is inadequate to characterize spatial or temporal patterns. Improving monitoring efforts will, for some parks, require installation of additional weather stations. For other parks, information can be obtained by downloading data for nearby stations from other networks, particularly the NWS COOP network.

Determining patterns and trends in air quality and climate conditions requires extended time series data. National parks, as long-term protected areas, are clearly advantageous locations for such monitoring efforts. As there are a vast number of issues to be addressed, partnerships with other agencies and universities are essential for these monitoring programs.

ACKNOWLEDGEMENTS

Many thanks to Fritz Klasner (PACN I&M) who worked on an early draft of this report. Thanks to Linda Pratt for providing the Ecological Context section. I also want to thank the following individuals for providing information about their research activities and/or offering comments and suggestions for this report and for the identification of vital signs for air quality and climate in the PACN: John Barnes (NOAA CMDL), Tamar Elias (USGS HVO), Tom Giambelluca (UH Manoa), Barry Huebert (UH Manoa), Roy Irwin (NPS), Lloyd Loope (USGS PIERC), JP Michaud (UH Hilo), Jeff Sutton (USGS HVO), Lisa Young (Hawaii DOH).

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APPENDIX A: ACRONYMS

Parks	Long Form	Notes
PACN	Pacific Island Network	NPS IM network
ALKA	Ala Kahakai National Historic Trail	Hawaii
AMME	American Memorial Park	Saipan, CNMI
HALE	Haleakala National Park	Maui

HAVO	Hawaii Volcanoes National Park	Hawaii
KAHO	Kaloko Honokahau National Historical Park	Hawaii
KALA	Kalaupapa National Historical Park	Molokai
NPSA	National Park of American Samoa	American Samoa
PUHE	Puukohola Heiau National Historical Park	Hawaii
PUHO	Puuhonua o Honaunau National Historical Park	Hawaii
USAR	USS Arizona Memorial	Oahu
WAPA	War In The Pacific National Historical Park	Guam
Miscellaneous		
AQRV	Air Quality Related Values	
ARD	Air Resources Division	NPS
CAA	Clean Air Act	
CASTNet	Clean Air Status and Trends Network	NPS/EPA joint project
CCGG	Carbon Cycle Greenhouse Gas group	part of NOAA CMDL
CMDL	Climate Monitoring and Diagnostics Laboratory	NOAA
CNMI	Commonwealth of the Northern Mariana Islands	
CO	Carbon monoxide	EPA criteria pollutant
CO_2	Carbon dioxide	
COOP	Cooperative Observer Programm	NOAA -NWS national volunteer weather observations program
COSPEC	Correlation Spectrometer	instrument used by HVO to measure SO_2
CPC	Climate Prediction Center	NOAA NWS
DOH	Department of Health	Hawaii
ENSO	El Niño Southern Oscillation	
EPA	Environmental Protection Agency	
H_2S	Hydrogen Sulfide	
HaleNet	Haleakala Climate Network	USGS BRD & UH Manoa (Giambelluca)
HVO	Hawaiian Volcanoes Observatory	USGS
Hg	Mercury	
I&M	Inventory and Monitoring Program	NPS program
IMPROVE	Interagency Monitoring of Protected Visual Environments	
IPCC	Intergovernmental Panel on Climate Change	
KVC	Kilauea Visitor Center	at HAVO
NAAQS	National Ambient Air Quality Standards	
NADP/NTN	National Atmospheric Deposition Program/ National Trends Network	
NAMS	National Air Monitoring Stations	National Environmental Monitoring Initiative
NO2	Nitrogen dioxide	
NOAA	National Oceanic and Atmospheric Administration	
NPS	National Park Service	
NRCS	Natural Resources Conservation Center	USDA
NWS	National Weather Service	NOAA
O_3	Ozone	EPA criteria pollutant
OBOP	Observatory Observations Group	NOAA CMDL
PAR	Photosynthetically Active Radiation	
Pb	Lead	
PDO	Pacific Decadal Oscillation	
PEAC	Pacific ENSO Applications Center	partnership of multiple institutions
PM	Particulate Matter	
PM10	Particulate matter smaller than 10 micron	
PM2.5	Particulate matter smaller than 2.5 micron	
POP	Persistent Organic Pollutants	such as PCB, DDT, HCH, Hg
PRISM	Parameter-elevation Regressions on Independent Slopes Model	Climate modeling tool taking topography into account; developed by SCAS/OSU

PRIMENet	Park Research and Intensive Monitoring of Ecosystems Network	EPA and NPS joint program
PSD	Prevention of Significant Deterioration Program	established by CAA
RAWS	National Interagency Remote Automated Weather Station Network	
SCAS/OSU	Spatial Climate Analysis Center/Oregon State University	
SLAMS	State and Local Air Monitoring Stations	EPA
SO_2	Sulfur dioxide	
TWI	Trade Wind Inversion	
UHSLC	University of Hawaii Sea Level Center	
UNEP	United Nations Environmental Programme	
USGS WRD	US Geological Survey Water Resources Division	
UV	Ultraviolet Radiation	
Vog	Volcanic smog	mixture of SO_2 and aerosols
VOGNET	vog monitoring network on the island of Hawaii	collaboration between NOAA Mauna Loa Observatory and 6 Hawaii Island high schools
WERI	Water and Environmental Research Institute	University of Guam
WIMS	Weather Information Management System	USDA Forest Service
WRAP	Western Regional Air Partnership	collaborative effort of tribal governments, state governments and various federal agencies
WWF	World Wildlife Fund	